The Origin and Evolution of the Deep Space Network

NA SA's system for communicating with solar-system exploration spacecraft began as a Cold War crash program, but its evolution was carefully planned from the start

Thirty-four years ago, a single principal antenna, installed the previous year (1 958) on a crash basis in an isolated location of the Mojave Desert of California, supported Pioneer 4, the first United States spacecraft to escape the Earth's gravitational pull and travel toward another solar-system body, namely the Moon, the nearest such body to Earth. 1 hat lone antenna, situated near the Goldstone Dry Lake Bed within the Department of the Army's Fort Irwin, would become the cornerstone of NASA's Deep Space Network, a system currently composed of 13 antennas of various designs and sizes that collectively have the capability of continuously communicating with spacecraft at distances ranging from high altitudes above the E arth to the outer edge of the solar system.

When the Goldstone antenna was procured, however, NASA had not yet come into being. It was instead the Department of Defense that provided the funding for the procurement, fabrication, erection, and testing of this antenna during a relatively short eight-month period in 1958. 1 he antenna, as well as the series of early lunar-probe attempts of which Pioneer 4 was a part, was, as we shall show, approved on a crash-program basis as one aspect of the Cold War then raging between the United States and the Soviet Union. It would not have been surprising if an antenna so hurriedly manufactured and installed for a short-term goal would have been subsequently abandoned when NASA began setting up a permanent system for later lunar and planetary probes. The fact that it was not was a reflection of careful planning by the procurer of the Goldstone antenna, a group of engineers at the Jet Propulsion laboratory (JPL), an Army facility in Pasadena, California, that became a part of NASA in late 1958. The early evolution of the Deep Space Network illustrates how a major communication system can be firmly established through a combination of carefully chosen initial elements, put in place during a period of limited time and funding, and later additions, installed as requirements become more demanding and further resources (such as funding and cooperating agencies) become available.

The Cold War origin of solar-system exploration

An official requirement for a system to communicate with space probes developed for the first time on 27 March 1958, when the Eisenhower Administration, through the Department of Defense's new Advanced Research Projects Agency, authorized a program of five lunar-probe attempts, three by the Air Force and two by the Army, all to be conducted within a year. The Administration publicly characterized the program (shortly to be named Pioneer) as a scientific project--an effort "to determine our capability of exploring space in the vicinity of the moon, to obtain useful data concerning the moon, and provide a close look at the moon." Archival records show, however-, that the major impetus for the program's approval was a desire by many inside and outside of government to find some quick means of restoring international prestige to the United States, after the Soviet Union's successful orbiting the previous October of Sputnik . . . 1, the world's first artificial satellite, had shattered a widely-held perception of American technological superiority.

In the six months between this event and Pioneer program announcement, in fact, numerous proposals for immediate "Moon shots" had been submitted to the Pentagon, and many cited the perceived Soviet threat. One of the first institutions to do so was JPL. In a proposal entitled "Project Red Socks" issued on 21 October 1957, *the* lab observed that the launching of Sputnik 1 less than three weeks earlier "has had a tremendous impact on people everywhere" and that it "has significance which is both technical and political." The proposal stated that it was "immediately imperative that the United States regain its stature in the eyes of the world by producing a significant technological advance over the Soviet Union." Pointing out that JPL had "some fairly sophisticated instrumentation and communication" capability that would allow it to achieve a successful lunar flyby mission, the lab advocated that the country "go to the moon instead of just going into orbit."

JPL was not alone in perceiving a potential political benefit deriving from a successful lunar mission. Ramo Wooldrige's newly formed Space Technology Laboratories (STL), located in Los Angeles, California, argued, in a proposal entitled "Project Baker" issued on 27 January 1958, that an early lunar flight with a moderate payload of scientific instruments could make a determination of conditions on the Moon that would be valuable for planning later flights with much heavier payloads that were certain to come within a few years. The firm also suggested, however, that "Of greater national importance may be the prestige of sending the first rocket to the moon, with clear proof that it reached its objective. "

Scientists and politicians, however, were initially not enthusiastic about these and other lunar-probe proposals. JPL director William t{. Flickering recalled that members of the Office of Defense Mobilization's Scientific Advisory Committee (ODMSAC) "were not sure that [the Red Socks proposal] was more of a stunt, as it were, and were not really that enthusiastic about it from a scientific point of view. " Deputy Secretary of Defense Donald A. Quarles testified before Congress in late November 1957 that he found "no cause for national alarm" in the existence of the USSR's Sputnik satellites and argued that the United States "must not be talked into 'hitting the moon with a rocket' just to be first, unless by doing so we stand to gain something of real scientific or military significance. " Eisenhower himself told colleagues that he would not be drawn into a "pathetic race" with the Soviet Union, and he characterized a lunar probe as "useless. "

The views of the scientists and politicians regarding "Moon shots" gradually changed, however, especially after the United States' first attempt to launch a satellite (Vanguard) on 6 December 1957 ended in spectacular failure--the explosion of the first stage of the launch vehicle within seconds of liftoff was recorded on live television. On 17 February 1958 the Space Science Panel of the new President's Scientific Advisory Committee (reorganized from the old

ODMSAC) held a meeting in the Executive Office Building (next to the White House) at which panel member Herbert York announced, to attending representatives from JPL and S-IL, that "it had been decided to attempt a lunar mission with the objectives of: a. Making contact with the moon as soon as possible, but with the limitation, b. 1 hat the contact be of a type that has significance such that the public can admire it. " York further stated that the panel had concluded, given the second objective, that "some kind of visual reconnaissance" (e.g., a camera to take a picture of the back side of the Moon) was the most significant experiment that a lunar vehicle could carry. PSAC's endorsement of an early lunar mission would lead to the aforementioned Pioneer program authorization in late March.

Supporting the Pioneer probes: STL's short-term approach

The Pioneer program would require simultaneous development of launch vehicles, spacecraft, and ground-support stations that would transmit commands to the spacecraft, determine their positions, and receive data from them. The stations were important, for without them no close-up photograph of the Moon could be obtained and, more fundamentally, no confirmation that the spacecraft were anywhere near the Moon was possible.

But what kind of network of stations should be set up? Should it be designed solely to support the Pioneer program and its limited objective of photographing the Moon? Or should a more elaborate system be constructed that would meet not only the requirements of the pioneer program but also the anticipated needs of future programs not yet authorized?

STL, initially under the leadership of Frank Lehan, had little choice but to undertake the short-term approach. Because of the more ready availability of their launch vehicles (Thor IRBM and Vanguard upper stages, the. three Air Force probes would be launched first, beginning in mid-August 1958. I-his situation would allow the Air Force and STL the initial opportunity to reap the glory of a successful first lunar mission, but it allowed the latter less than five months to set up a network of ground-support stations.

By necessity, the antennas used at the two principal stations had to be already erected or at least manufactured, and their locations were governed by the roles they would play in communicating with the lunar probes while they were in the vicinity of the Moon. For example, a 60-ft-diameter parabolic antenna with a transmitter--a modification of the l"LM-18 antenna that Radiation, Inc., was currently manufacturing for use in the forthcoming Air Force Discoverer reconnaissance-satellite program--was installed at South Point on the island of t lawaii because there it would have a favorable look-angle at the probes at the time of their fourth-stage retrorocket firings.

S-l L planned for the picture taking to occur as soon as the probes entered orbit, before anything might go wrong with the spacecraft, and this milestone was expected to occur over about the 0° longitude, which crossed parts of Europe and Africa. Lehan and his colleagues knew that the quality of the picture taking would improve as the diameter of the receiving ground-based antenna increased, but the time constraint, as well as diplomatic and funding considerations, did not permit the installation overseas of a new large antenna, possibly one 200 ft or more in diameter. I-he University of Manchester's 250-ft-diameter radio telescope at Jodrell Bank, however, already existed. A secret meeting between an Air Force officer and Bernard Lovell, the director of the Jodrell Bank facility, enabled STL to install temporarily an appropriate feed and other specialized equipment on the antenna in support of the picture-taking activity.

S1L engineers appear to have given little thought initially as to what might constitute a permanent system of stations for supporting an ongoing program of unmanned solar-system spacecraft exploration, and whether any of the antennas installed or modified in 1956 could become part of such a permanent system. JPL engineers, by contrast, began planning for a permanent system even before the Pioneer lunar-probes authorization was issued.

JPL looks to the future

Probably the strongest advocate for such a permanent system was Eberhardt Rechtin, chief of JPL's Electronics Research Section. More aware than his colleagues in the propulsion field of the likely advances in electronics and the potential distances that could be reached in space communications (I-able xx), he strongly urged, in the spring of 1958, the development of a launch vehicle (Juno IV) capable of delivering a 550-pound payload to the Moon and a 300-pound payload to the planet Mars. Such a vehicle, he argued, was needed "to accomplish significant missions competitive with the USSR; lesser vehicles will only keep us to the rear in accomplishment of missions. " Juno IV'S capability of soft landing on the Moon, Rechtin pointed out, could eventually permit the establishment of "quite stable" radio and optical telescopes on the lunar surface.

As for Mars, Rechtin argued that the often discussed similarity of this planet to the Earth would make photographic exploration of it "one of the major goals of prestige between the United States and the USSR. " Looking further into the future, he noted that meteorological and surface-condition instrumentation could determine "the practicality of putting people on Mars." Rechtin predicted that "if conditions on Mars are even slightly more suitable than anticipated, the past success of the human race in new exploration will unquestionably start the drive to Mars. Based on human history, it will then be first come-first served on Mars. " Left unsaid, but most likely implied, was the desire that the United States get there before the USSR.

Rechtin was not alone at JPL in perceiving Mars and other planets of the solar system as the ultimate goals of space exploration. Albert Hibbs, who became the first chief of JPL's new Space Science Division, recalled in an interview that "[W]e wanted a good challenge, and that was the technical challenge, getting a useful payload to a planet. It was really tops in engineering challenge--propulsion, guidance, communications, you name it. "

It was for this envisioned ambitious program of lunar and planetary missions that JPL , and particularly Rechtin and his fellow communications engineers, desired in early 1958 to build a permanent network of stations that could transmit commands to spacecraft, determine their positions relative to the Earth or other objects, and receive scientific and engineering telemetry data from them. Rechtin's conception of a permanent network was based on a consideration of the apparent motions of space probes and a requirement, sure to be imposed by any funding agency, to keep costs to a minimum.

He knew that after a space probe launched from Cape Canaveral completed its injection phase, during which it would move rapidly to the east, it would (due to a decreasing angular velocity as it gained altitude) have an apparent motion from east to west that closely approximated that of a fixed radio source. During this post-injection phase the greatest components of the probe's apparent motion will be due to the rotation of the Earth, and such rotation obviously results in the probe apparently moving across the sky from the eastern to the western horizon of a particular antenna station once each day. Simple geometry dictates that the minimum number of principal antenna stations that permits continuous, overlapping monitoring (necessary as missions became more complex and longer in duration) after the injection phase is three (Figure xx). Because the world is divided into 360° of longitude, the three stations should ideally be located 120° apart in longitude.

Confident that solar-system exploration would "continue in the coming years," Rechtin and his colleagues--particularly Walter K. Victor, head of the Electronics Research Section, and Robertson Stevens, head of the Guidance Techniques Research Section--sought a communication system design that would “be commensurate with the projected state of the art, specifically with respect to parametric and maser amplifiers, increased power and efficiency in space vehicle transmitters, and future attitude-stabilized spacecraft .“ Because of the later availability of the Army lunar-probe launch vehicles (Jupiter IRBM and a cluster of upper stages employing Baby Sergeant rocket motors), they had just enough extra time to design and install a communication system that could not only support the Pioneer lunar probes, but also evolve into a permanent system for supporting future solar-system exploration spacecraft.

Choosing an antenna design

With regard to antenna design, Rechtin, Victor, and Stevens desired an instrument with an accuracy of *2* minutes of arc or better, Operation on a 24-hour basis dictated that this accuracy would have’ to be maintained regardless of solar exposure and rapid ambient temperature changes. Furthermore, “since missile [launch vehicle] firings cannot be held up because the wind is blowing somewhere around the earth nor can the bird [spacecraft] be whistled back from a space mission when the wind comes up, ” the antenna would have to be usable in winds of 60 mph and be capable of withstanding (in a stowed position) winds of 120 mph.

Rechtin assigned William Merrick (head of the Antenna Structures and Optics Group) to identify an antenna design that could satisfy these demanding requirements. Confident that JPL would receive an lunar-mission assignment but aware that the " procurement, fabrication, and erection of the antennas would be the "longest lead time item" for carrying out such an assignment, Rechtin made this assignment on 7 February 1958, nearly seven weeks before the Pioneer authorization. Merrick concluded that the desired antenna would have to combine the best features of a precision radio-astronomy antenna and a precision guidance or tracking radar. Merrick recalled later that the radio astronomers and suppliers he consulted "questioned our sanity, competence in the field and/or our ability to accomplish the scheduled date [initially November 1958] even on an 'around the clock' basis."

Merrick and his colleagues rejected many existing antenna designs because of foreign manufacture, high cost, inadequate aperture, and/or acknowledged design flaws. Others, such as the CSIRO's 21 0-ft diameter antenna at Parkes, Australia, and NRAO's 140-f t-diameter antenna at Green Bank, West Virginia, were eliminated from consideration because these prototypes would not be completed until 1960 or later. 1 he Jodrell Bank type of antenna was rejected because it was "too big and expensive" and its design and assembly had required seven years.

Merrick and his colleagues ultimately chose a design that had been initiated at the Naval Research laboratory in 1953, developed further by t-toward W. 1 atel at the Carnegie Institution of Washington, and refined by the Associated Universities, Inc. (AUI), and that had just been completed by the Blaw Knox manufacturing company in Pittsburgh. The 26-m-diameter (85-ft) antenna had a cantilevered-equatorial mounting and very large hour-angle and declination drive gears that gave high driving accuracy for relatively low tooth accuracy and a low tooth loading during high winds. Blaw Knox, which priced the antenna at about $250,000, had already received orders from the University of Michigan and AU I (for erection at Ann Arbor and Green Bank, respectively), but neither had been completed when JPL placed an order, with ARPA's approval, for three antennas in April. Eventually, citing national priority, the Army was able to move one of these probe-supporting antennas to the front of the manufacturing line,

Choosing a station site

That first antenna was slated for a site in the United States. Rechtin later recalled the planned overseas stations "so rapidly became bogged down in approval red tape" that their earliest possible activation date gradually moved beyond the second Army lunar-probe attempt. Three stations would be essential for possible future long-duration flights to the planets, but the limited objective of the Army lunar probes allowed JPL engineers to make do temporarily with one antenna. Continuous around-the-clock monitoring of the probes was of course impossible, but JPL engineers could deliberately select a trajectory that would cause them to arrive at the vicinity of the Moon when they were in the line of sight of the single principle antenna. Also, they, unlike their counterparts at STL, had no need for a separately located transmitter station. The probes were slated to fly by the Moon (thus requiring no retrorocket firing commands), and the desired pictures would be taken automatically when a photocell mechanism indicated that the probes were within a certain distance of the Moon.

With the expectation that probes would eventually be sent to the planets and thus their received signals would be extremely weak, JPL communication engineers desired a site for their single initial principal antenna that would minimize outside radio interference as much as possible. In addition to avoiding areas with power lines, radio stations, radar transmitters, and/or considerable numbers of aircraft passing overhead, they sought in particular a natural bowl, so that the surrounding terrain could shield the antenna from nearby towns and passing vehicles. I-he underlying soil had to be suitable for accurate and stable support of the antenna, and an access road, for transport of the sizable steel components of the antenna, would have to be built for what was likely to be a remote site. Finally, the more immediate funding and time constraints of the Pioneer program mandated use of Government-owned land.

Thanks to a search two years earlier for an off-lab site to test rocket engines, JPL engineers were aware that an area near Goldstone Dry [Lake at the Army's Fort Irwin, located in the Mojave Desert about 150 mi northeast of Pasadena, would meet these criteria. After General John B. Medaris, the head of the Army Ballistic Missile Agency, in mid-May 1958 overruled another general who wanted to use the Goldstone area for a proposed missile firing range, the work needed to convert the site into the desired antenna station swung into high gear. Carefully avoiding unexploded ordinance lying in the area, workers constructed access roads, laid the antenna foundation, and constructed support buildings during the late spring and early summer. Soon after the steel components arrived in mid-August, a crew from the Radio Construction Company began erecting the antenna. After the crew completed its work two months later, the feed was installed and various optical and radio-frequency tests were conducted to establish the system tracking accuracy.

Choosing an operating frequency

Unlike their counterparts at STL, JPL engineers, led by Victor, chose not to operate at the 108 MHz frequency being used for the Vanguard and Explorer satellites. With future missions clearly in mind, they noted in an early report that the presence of interference at frequencies below 500 MHz would "seriously limit the growth potential of any space communication technique" using a frequency in this region. Victor at first favored a frequency in the region between 1365 and 1535 MH7, where he anticipated significant hardware developments for improving receiver sensitivities because the region bracketed the astronomically important 21 -cm hydrogen line. Colleagues soon convinced him that a stable, efficient spacecraft transmitter operating in that region could not be built in time for the Pioneer probe missions, however, and he instead opted for a 960 MHz (L-band) operating frequency.

The hard work that STL and JPL communications engineers expended in setting up their respective systems of antenna stations (which included several with smaller antennas at launch-point and downrange locations) in relatively short time periods paid off in very satisfactory operation during the actual missions. Various rocket failures, however, prevented all but the second Army probe (launched on 3 March 1959) from reaching escape velocity, and this probe (Pioneer 4) passed too far away (37,000 mi) from the Moon to activate the camera system. By then, the USSR's Luna 1, launched on 2 January, had already passed within 6,000 mi of the lunar surface, Luna 3, launched on 4 October 1959, took the first photographs of the far side of the Moon.

Gaining approval for a permanent system

The expansion of JPL's ground-support system for the Pioneer lunar probes into a complete worldwide three-station network was not inevitable. The first challenge to JPL's plans came from STL, which in late June 1958 issued a proposal that called for the construction of three 250-f t-diameter antennas to be located in Hawaii, Singapore or Ceylon, and near the eastern coast of Brazil. The firm claimed that discussions with JPL and "a thorough analysis of foreseeable space programs" (including a series of new probes aimed at the planets Venus and Mars that STL was simultaneously proposing) indicated that "the long-range interests of the United States in high-altitude communications relay satellites and in interplanetary space programs could best be served" by the establishing of two networks of three stations each, placed at intervals of about 60° around the equator of the earth.

Rechtin thought otherwise; he considered the proposal "a ploy to block JPL's [network plans] by forcing a study and reconsideration of JPL's ARPA order [for three 26-m-diameter antennas]. " He may have been right. The estimated overall cost of STL's proposed new system was $34 million. How STL expected the government to approve such a large sum in so short a time (the company claimed that it could "realistically" complete construction of the first antenna in Hawaii by 15 October 1959) is unclear. The proposal, in any case, was not funded.

A greater threat came in early July 1958, when Deputy Secretary of Defense Donald Quarles questioned why STL and JPL were developing two separate systems for supporting the Pioneer lunar probes. In response, Rechtin traveled immediately to Washington, and in a 8 July meeting at the Pentagon with Richard Cesaro, chairman of an ARPA advisory panel on tracking, he acknowledged that JPL was using the extra time afforded by the later launch dates of the Army lunar probes "to begin a longer range space tracking program using the proper parameters. " These parameters included the 960 MtIz operating frequency and the 26-m-diameter antennas that would be "capable of tracking all vehicles from a 330-mile altitude satellite to space probes to Mars. "

Cesaro was impressed with Rechtin's presentation, but asked that JPL prepare a formal proposal for a "World Net" that would consider as well the communications requirements of other intended ARPA space programs. JPL's Proposal for Interplanetary T-racking Network, issued on 25 July, considered (despite its title) such requirements for six different space programs that the United

States planned to undertake--manned space flight, meteorological satellites, reconnaissance satellites, communications satellites (both geosynchronous and low-Earth-orbiting), scientific satellites, and space probes--as well as the detection of "noncooperative" (i.e., foreign) satellites. Comparing all the requirements (Table xx), Rechtin and several colleagues suggested that two principal overseas antennas could be most advantageously placed, for supporting space probes and certain other space programs, at Woomera, Australia, and somewhere in Spain.

Cesaro was once again impressed with JPL's work, and indicated to Rechtin his intention to recommend that "all the tracking and computational facilities should be handled under Army administration with JPL as the technical arm. " Rechtin was delighted with this recommendation, but nevertheless cautious. He believed that Cesaro "may be way over optimistic" in thinking that "ARPA certainly has the power to do this and would put down any rebel lion." In particular, Rechtin warned a JPL colleague that "we should expect considerable uproar from the Naval Research Laboratory who probably figures it knows more about tracking than anybody else. " The NRL's Radio Tracking Branch, under the leadership of John T. Mengel, had developed the Minitrack tracking system for the Vanguard satellite program.

1 he basis for Rechtin's caution was his knowledge that Congress in the summer had approved President Eisenhower's request for establishing a civilian space agency, and as a result the Nationa Aeronautics and Space Administration was slated to come into bei ıg on 1 October 1958. NASA's impending formation meant

that ARPA was gradually losing its status as the interim United States space agency.

Furthermore, by early January it became clear that not only did the Defense Department want a station network separate from any set up by NASA (because their need for secrecy conflicted with the new space agency's professed openness), but also those involved in setting up NASA's manned-space-flight, satellite, and space-probe programs desired separate station networks. As Rechtin feared, JPL's plans were also strongly opposed by Mengel, whose group had already been transferred into NASA. Mengel claimed that the installation of more Minitrack stations was more essential than than overseas space-probe-supporting stations, because "the satellite experiments and their associated tracking was more important [than space probes] as far as NASA plans were concerned."

Despite Mengel's views, on 10 January 1959 NASA, which had supported since early November JPL.'s development of a recommended set of future lunar and planetary probes and had also acquired JPL from the Army, signed an agreement with the Department of Defense that called for, among other things, installation of stations for deep-space probes at Woomera and in South Africa. The preference by NASA and JPL for South Africa as the host country for a dedicated probe-supporting station derived from the fact that most space probes would pass over southern Africa during the injection phase of their flights, when it was vitally important to establish their actual trajectories for later accurate pointing of the other probe-supporting antennas.

Overseas expansion

In establishing the overseas stations, Rechtin insisted that they be operated by local nationals rather than "displaced Americans." Desiring the best possible performance from each of the stations, he reasoned (and was supported by later experience) that this could be obtained from professionals "proud of their work, held responsible, and cooperatively competitive in spirit." NASA and JPL fortunately identified in Australia and South Africa organizations--the Department of Supply's Weapons Research Establishment (WRE) and the Council for Scientific and Industrial Research's National Institute for Telecommunication Research (NITR), respectively--that were eager to cooperate in the establishment of the network for supporting space probes.

The WRE was managing the Woomera rocket range at which the United Kingdom and Australian governments had been conducting high-altitude missile firings over the past decade, and WRE superintendent Bill Boswell anticipated that the addition of an 26-m-diameter antenna could not only expand support of these firings but also ensure Woomera "a leading place in satellite and space research." NITR director Frank Hewitt anticipated that the antenna would be a "most valuable scientific tool" that could be used between missions to conduct radio-astronomy research. He also believed that the techniques involved with the antenna would be fundamental to future intercontinental communications--an activity of great performance to a country quite distant from Europe and the

United States--and that therefore the NITR should become familiar with them.

NASA sent site-survey teams to Australia and South Africa in February and September-October 1959. With extensive assistance from WRE, NITR, and other local officials, NASA and JPL eventually identified and selected two appropriate sites: a semicircular bowl open to the south at the edge of a dry lake bed known as Island lagoon about 18 mi from the village of Woomera and about 30 mi south of the range head, and a Y-shaped valley near the town of Hartebeesthoek about 30 mi northwest of Johannesburg and 18 mi west of Pretoria.

NASA funded the construction of the overseas stations and sent field crews to erect the antennas and install the electronics, but it was WRE and NITR that bore the responsibility for acquiring the land, constructing access roads and support buildings, and hiring staff to operate the station. With a new program of Ranger lunar-impact probes scheduled to be launched beginning in mid-1961, both agencies worked hard with NASA and JPL to ensure that the stations would be ready in time. NITR's success in doing so was made more difficult by delays (occasioned by the Sharpeville township disturbance and the Soviet Union's downing of a United States U-2 spyplane in March and May 1960) in the signing of a diplomatic agreement governing the station and other NASA facilities in South Africa, By the time Ranger 1 was launched on 23 August 1961, however, both stations were ready and the Deep Space Instrumentation Facility (renamed the Deep Space Network in 1963) at long last had become operational.

Subsequent evolution

Anticipating that space probes would become more sophisticated in future years and would eventually travel beyond the orbits of Venus and Mars (in contrast to the fixed range of Earth-orbiting satellites), Rechtin sought and received from NASA a continuing commitment that a relatively fixed portion (generally about 10 percent) of the Deep Space Network budget would be devoted to research and development. This commitment allowed the Network to evolve in a timely way in subsequent years, as new requirements were anticipated and means to meet them were conceived, tested, and installed.

In early 1961, for example, Rechtin recognized that NASA's deep-space program would soon be expanding very rapidly (further Rangers, Mariner flybys of Venus and Mars, Lunar Orbiters, Surveyor lunar soft-landings, and Apollo manned lunar landings). He could foresee occasions when "so many flights [would be] operating at any one time . . . that a single antenna at each DSIF station could not conceivably carry the load." Rechtin envisioned a future situation when project managers could be "confronted with impossible choices between probes measuring dangerous solar flares, observing violent effects on Mars, roving among the crevasses on the Moon, and carrying men into deep space."

New 26-m-diameter antennas were thus needed (to be accompanied by a change in operating frequency to S-band (2388 MHz)), and the first of these antennas was installed at Goldstone in early 1962. Although the Woomera and Hartebeesthoek stations would continue to operate through the early 1970s, neither was the site of the new overseas antennas. WRE had difficulties fully staffing the Woomera station, due to its isolated location (in the outback about 200 mi north of Adelaide) and insufficient housing for staff members and their families. Although the WRE gradually resolved the staffing and housing problems at Woomera, the long-term solution was to find a new adequately shielded site nearer a center of population. Officials from JPL and the Australian Departments of Supply and Interior eventually identified such a site in the Tidbinbilla Valley, located 11 rni southwest of Canberra (Australia's capital) along the northeastern edge of the Australian Alps. The station constructed at this site became operational in March 1965.

NASA and JPL were quite satisfied with NITR's operation of the station at Hartebeesthoek, but Rechtin in particular was fearful that relations between the governments of the United States and South Africa might eventually deteriorate, due to condemnation in the United States and abroad of the latter's apartheid policies, to a point where operations at this station would have to be sharply limited and curtailed. He argued that any expansion of the station would make it more costly for NASA to duplicate the station elsewhere at a later date.

An initial survey of sites in Italy proved unsuccessful, A survey team found natural bowls on the island of Sardinia, but such a location would be difficult to support logistically. Potential sites near Rome would not have this difficulty, but they were less well shielded and would create coverage gaps between a station here and the one at Goldstone.

NASA and JPL ultimately chose a site in a valley near the village of Robledo de Chevala, 31 mi west of Madrid, Spain, for the location of a 26-m-diameter antenna. A second such antenna was subsequently installed near the town of Cebreros, 8 mi southwest of Robledo de Chevala. These stations became operational in July 1965 and January 1967. Despite some misgivings about dealing with the Franco authoritarian government, NASA had been quite pleased with assistance rendered by the Spanish government's Instituto National de Técnica Aeronautic (INTA) in the operation of a Project Mercury station in the Canary Islands, and this organization became NASA's cooperating agency for the new Deep Space Network stations in Spain as well.

A major evolutionary step was the design and installation of new 21 0-ft-diameter antennas at Goldstone, Tidbinbilla, and Robledo de Chevala. These were built in response to the expected advent of more sophisticated spacecraft (as launch vehicles became more powerful), which would create a requirement for an increasing rate in the communication of data from the spacecraft back to Earth. JPL considered a number of alternatives for meeting this requirement--increasing the power of the spacecraft transmitter, electronic arraying of two or more 26-m-diameter antennas, and use of existing large radio-telescope antennas--but economics and availability considerations ultimately dictated the construction of new large antennas up to 250 ft in diameter. After two years of design studies and nearly four years of contract negotiation, ground preparation, support-building construction, and antenna erection, the first of the Deep Space Network's large antennas became operational in May 1966. Two other such antennas became operational at Tidbinbilla and Robledo de Chevalla in April and September 1973.

The Deep Space Network expanded the newer of the 26-m-diameter antennas at Goldstone in 1978 in order to add X-band (8.4 GHz) capability and increase the antenna gain (received signal strength) for the two Voyager outer-planet missions. Antennas at Tidbinbilla and Robledo de Chevala were similarly expanded in 1980, This improvement was sufficient for the Jupiter and Saturn encounters (1979-81) of the two spacecraft. The extension of the Voyager 2 mission to include encounters with the more distant planets Uranus in 1986 and Neptune in 1989, however, forced Voyager and Network engineers to find new means to compensate for a still more severe decrease in signal strength and thus avoid an undesirable great limitation on the science data return.

One means was the installation of new 34-m-diameter high-efficiency antennas (so-called because their reflector surfaces' are precision-shaped for maximum signal-gathering capability) at Goldstone in 1984, Tidbinbilla in 1985, and Robledo de Chevala in 1987. T-he 64-m-diameter antenna and the two 34-m-diameter antennas could now form a three-element array. This combination (together with a reprogramming of two of the Voyager computers to accommodate an image data compression technique) permitted a higher data rate (19 kilobits/see).

Because a still higher data rate would be needed to meet the imaging science requirements at Uranus and Neptune, Deep Space

Network engineers sought and received permission from Australia's Commonwealth Scientific and Research Organization to add temporarily (in 1986 and 1989) their 64-m-diameter radio telescope at Parkes to the Tidbinbilla array via a ground microwave link. The Network made use of a second interagency array in 1989, when the twenty-seven 25-m-diameter radio-telescope antennas of the National Radio Astronomy Observatory's Very Large Array in New Mexico were linked with the Goldstone's antennas.

One further step taken for the Neptune encounter was the extension of the 64-m-diameter antennas at each station to a diameter of 70 m and the the reshaping of their reflector surfaces to improve their efficiency. These improvements, which increased the effective signal capture of these antennas by 50 pecent, were completed at ~~Tidbinbilla and~~ Robledo de Chevala in ~~[xxxx]~~ and Goldstone in 1988.

The Deep Space Network continues to evolve even today. I-he original 26-m-diameter antennas installed in the 1958-61 period are no longer in service--the one at Goldstone is now a national monument, the one at Woomera has been scrapped, and the one at Hartebeesthoek is now used by South Africans for radio-astronomy research. The second set of such antennas (those extended to 34 m in the late 1970s) are nearing the end of their usefulness. I-he onset of metal fatigue and the mechanical limitations of their late 1950s design do not permit further upgrades to improve performance. The Deep Space Network will therefore soon be replacing these antennas with 34-m-diameter multifrequency bearn-waveguide antennas. These new antennas will allow critical weather-sensitive microwave components to be located in an equipment room in the antenna pedestal rather than on the rotating and tipping main reflector. The first of these new antennas was recently installed at Goldstone and will shortly become operational after completion of performance testing.

To probe further

The author is nearing completion of a book-length history of the Deep Space Network that will be based on published sources, oral history interviews, and unpublished documents in archives in the United States, Australia, South Africa, and Spain. Photocopies of the documentation supporting the book (and the article above) will be deposited in the JPL Archives. His article "Designing the United States' Initial 'Deep Space Networks . ..." IEEE Antennas and Propogation Magazine, vol. 35, no. 1, February 1993, pp. [xx], provides additional detail concerning the choices of antenna design, operating frequency, and antenna location made by STL. and JPL for supporting the Pioneer lunar-probe attempts of 1958-59.

William R. Corliss's A History of the Deep Space Network (NASA CR-151915, 1976) is an earlier work based primarily on published documents, Edward Mayes Walters' "The 'Partnership' Philosophy: Australian-American Space-Tracking Relations, " unpublished Ph.D. dissertation, University of Georgia, 1970, used unpublished NASA Headquarters documents to discuss the diplomatic process leading to the establishment of the Woomera and Tidbinbilla Deep Space Network stations and other NASA facilities in Australia.

Eberhardt Rechtin described how the Deep Space Network anticipated future requirements and developed means to meet them in his "long-Range Planning For the Deep Space Network," Astronautics & Aeronautics, vol. 6, no. [xx], January 1968, pp. 28-35.

For historical accounts of JPL's participation in NASA's unmanned solar-system exploration program, see Clayton R. Koppes, JPL and the American Space Program: A History of the Jet Propulsion Laboratory (Yale UP, 1982); William E. Burrows, Exploring Space: Voyages in the Solar System and Beyond (Random House, 1990); and Craig B. Waff, "The Struggle for the Outer Planets," Astronomy, vol. 17, no. 9 (September 1989), 44-52,

About the author

Craig B. Waff is a technical writer in the TDA-DSN Documentation Group at the Jet Propulsion Laboratory, a NASA field research center operated managed by the California Institute of Technology. Prior to assuming his present position in October 1992, he worked under two separate three-year contracts to JPL for the purpose of researching and writing histories of NASA's Project Galileo and the Deep Space Network. Waff was a co-winner of the National Space Club's 1989 Goddard Historical Essay Award.

The author would like to express gratitude to Nicholas A. Renzetti of JPL and to Sylvia D. Fries and Roger D. Launius of NASA Headquarters for supporting the contract under which the research for this article was conducted; to Eberhardt Rechtin, currently a professor of engineering at the University of Southern California, as well as many other current and former staff members of the Deep Space Network in the United States, Australia, South Africa, and Spain for agreeing to be interviewed regarding their involvement with the Network; and to archivists at JPL, the NASA Headquarters History Division Office, the Canberra and Melbourne branches of the Australian Archives, and the Council for Scientific and Industrial Research in Pretoria, South Africa, for locating historical documents.

LUNAR PROBE TLM-18 ANTENNA

Fig 1 STL Transmitter Antenna South Point, Island of Hawaii

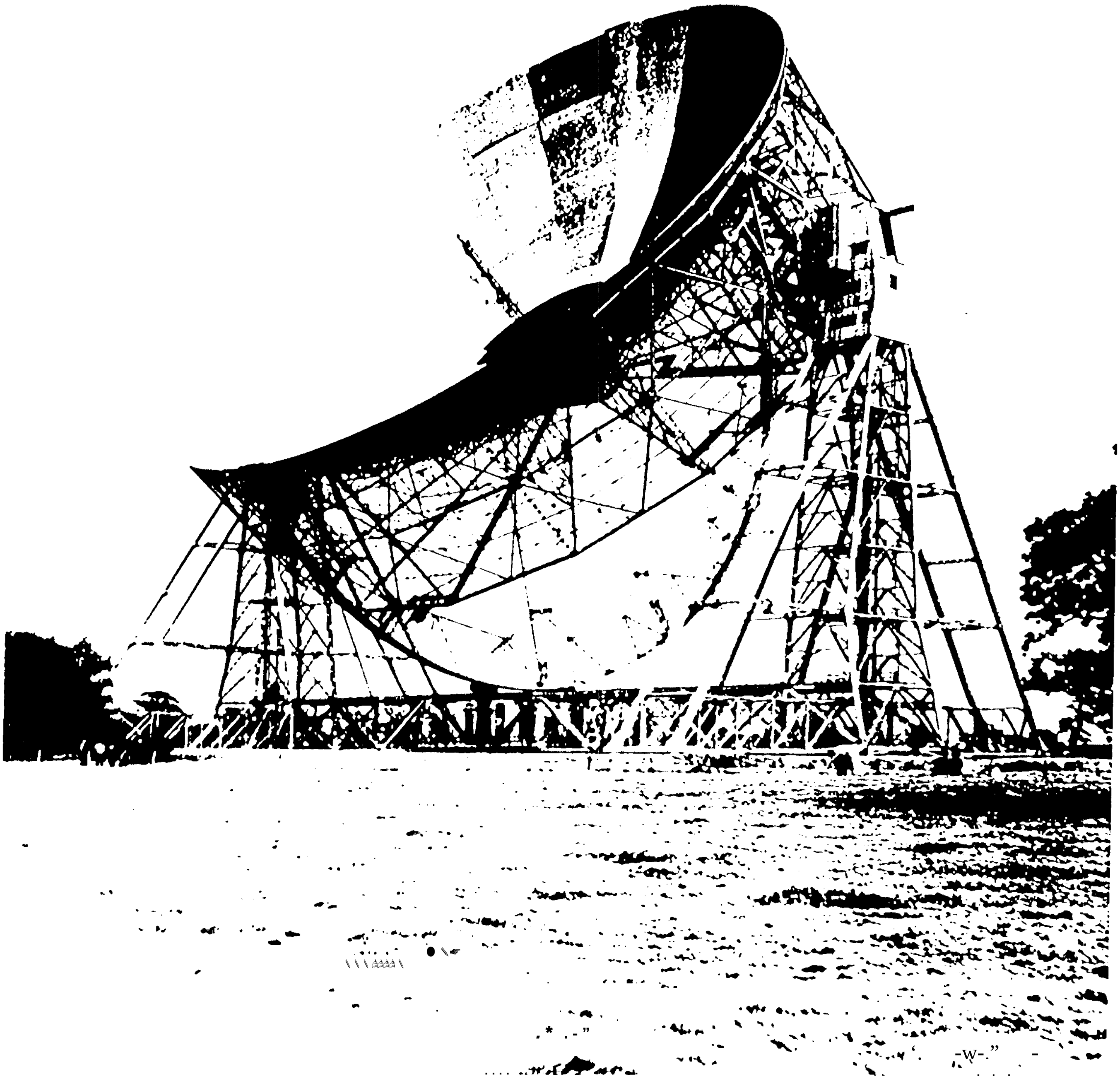


Fig 2 Jodrell Bank 250-Ft. diameter radio telescope

Summary of Illustrative Communication System Characteristics for Space Program

Characteristics	1958	1959	1960	Remarks
A. Space-to-Earth Path				
1. Space-to-earth frequency	1,000-2,000mc	1,000-2,000mc	1,000-2,000mc	Maximum S/N ratio: best compromise between tracking accuracy and angle acquisition.
2. Vehicle transmitter power	0.1 watt	1 watt	10 watt	Early use of solar energy,
3. Vehicle antenna gain	6 db	10 db	18 db	
4. Ground tracking stations	2	4	4	Three 85' tracking antennas in world net. One 8' tracking antenna at launch site.
5. Ground antenna	85' diam.	85' diam.	85' diam.	Gain at 1,000 mc 46 db
6. Beam width of ground antenna	0.8°	0.8°	0.8°	
7* Angle tracking accuracy	1 - 3 mils	1 - 3 mils	.1 - .3 mils	Use radio stars for calibration and compute for correcting angle data.
8, Ground receiver bandwidth	60 cps	25 cps	10 cps	Using oscillators with increased stability.
9. Ground receiver noise temp.	2000°K	1000°K	400°K	Using low temp. solid state techniques.
10. Ground receiver sensitivity	-148 DBM	-155 DBM	-165 DBM	
11. Space-to-earth range for S/N - 10 DB	350,000 mi.	3,500,000 mi.	50,000,000 mi.	
B. Barth-h-space Path				
1. Earth-to-space frequency	none	1,000 - 2,000mc	1000- 2000mc	
2. Ground transmitter power	none	10 KW	10 KW	
3. Ground transmitter stations		1	2	
4. Ground transmitter antenna	none	85'	85'	Additional 85' dishes required.
5. Doppler velocity	one way	two way	two way	
6, Range tracking accuracy		100 miles	100 miles	
7 Vehicle receiver BW		100 cps	100 cps	
8 Vehicle receiver noise temp.		30,000°K	3,000°K	
Vehicle receiver sensitivity		-134 DBM	-144 DBM	
Earth to space [illegible]				

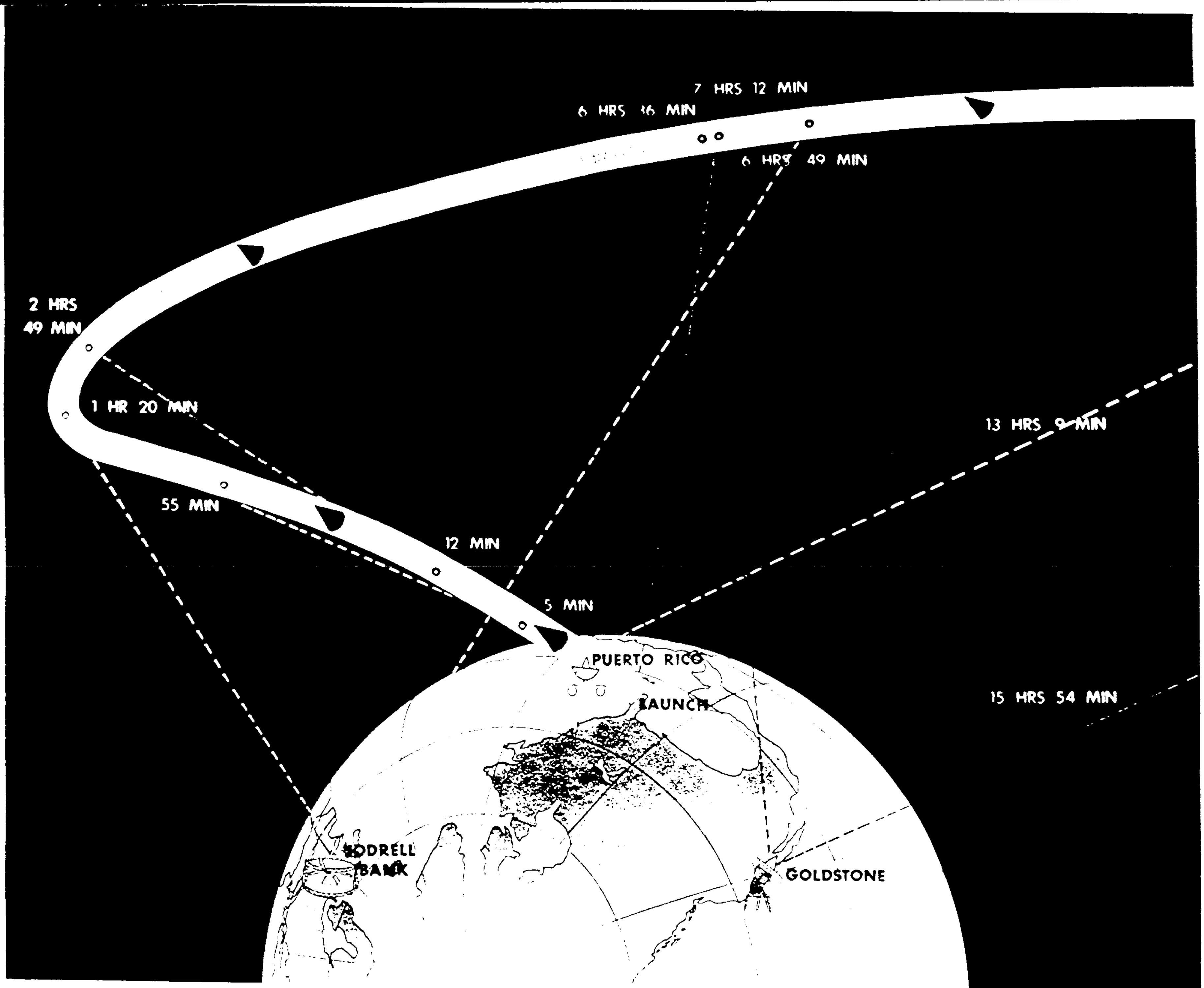
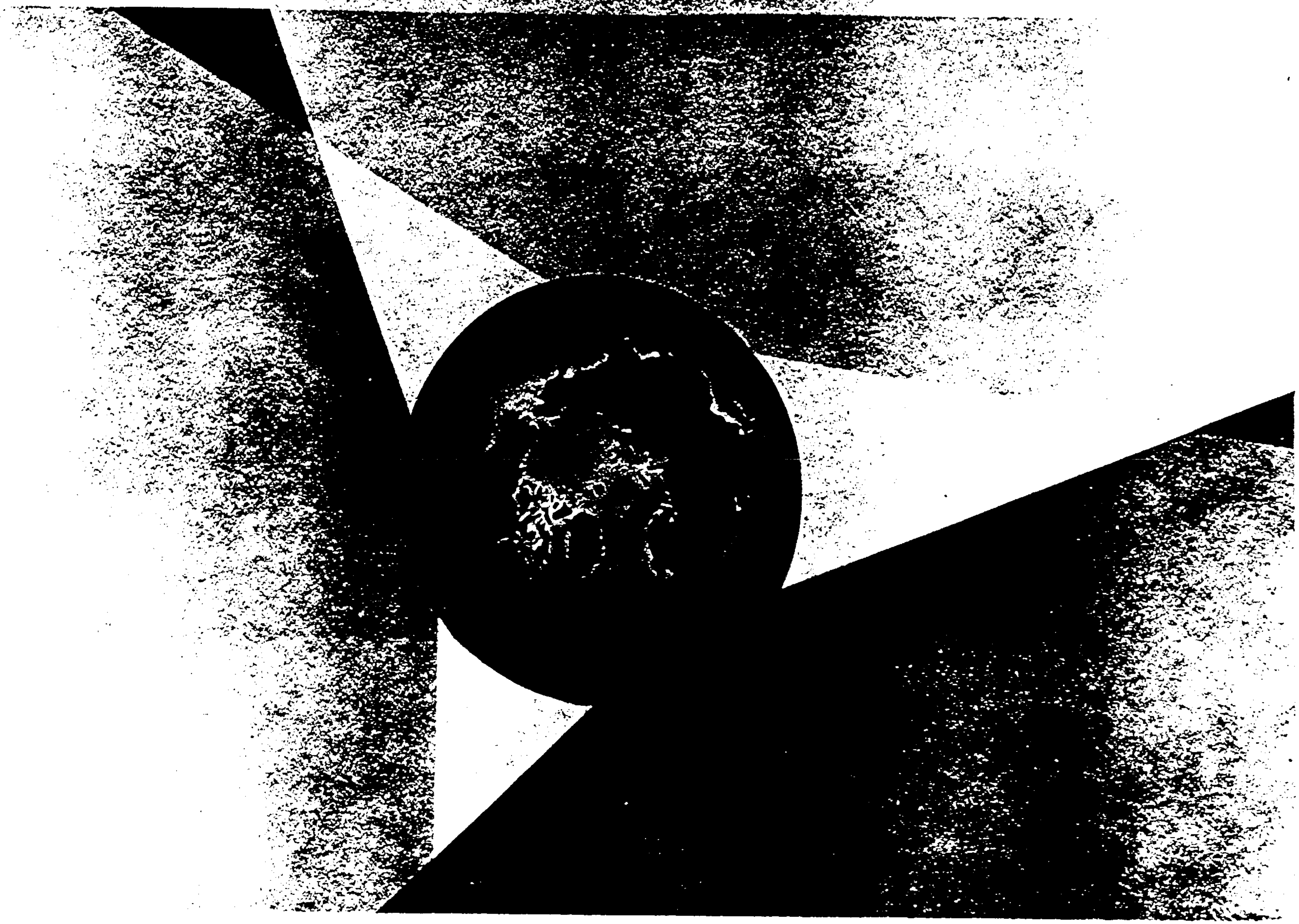


Fig 3 Injection Phase of Space Probe

DEEP SPACE COVERAGE FROM THREE STATIONS



Fg 4

~~Figure #~~ 4

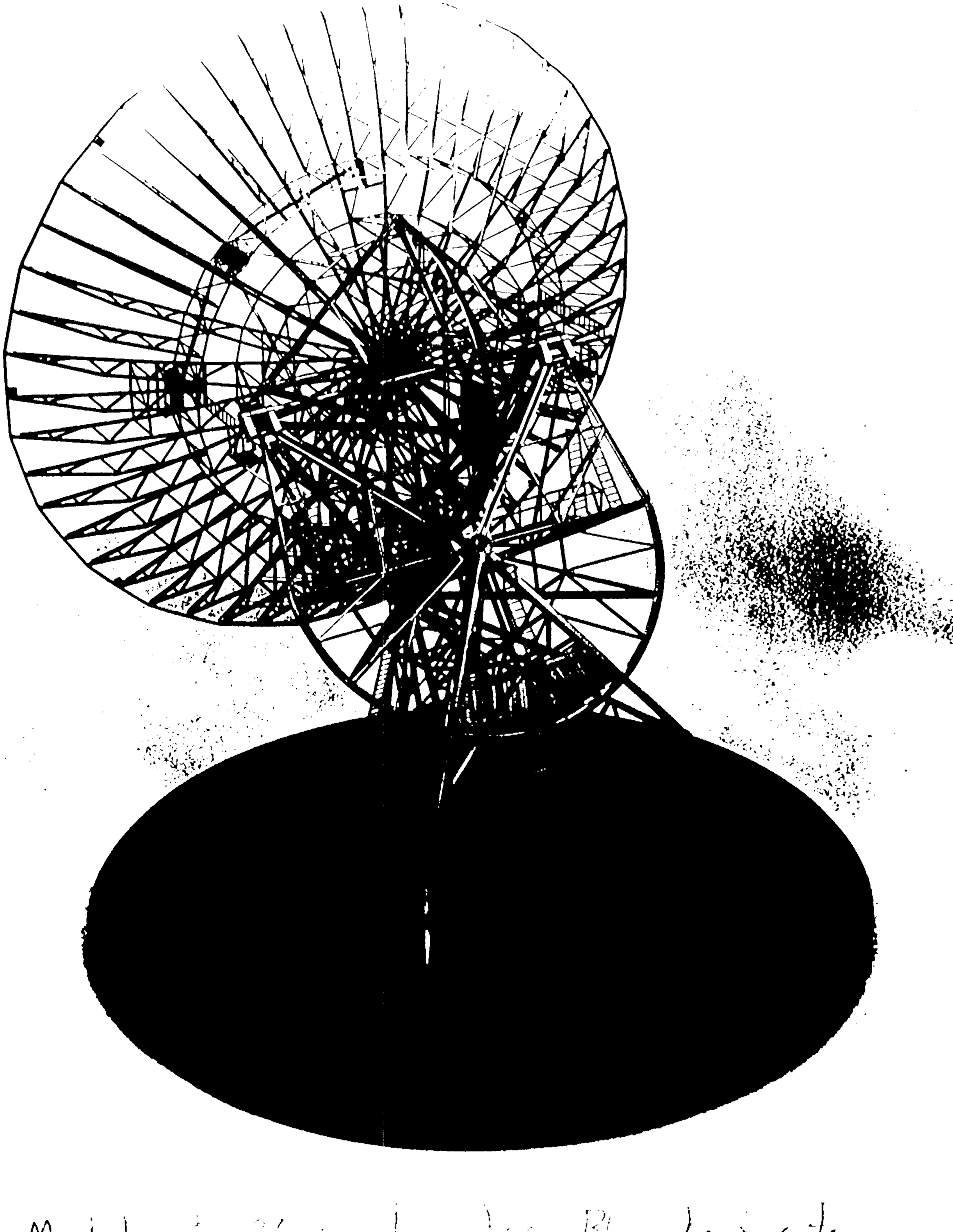
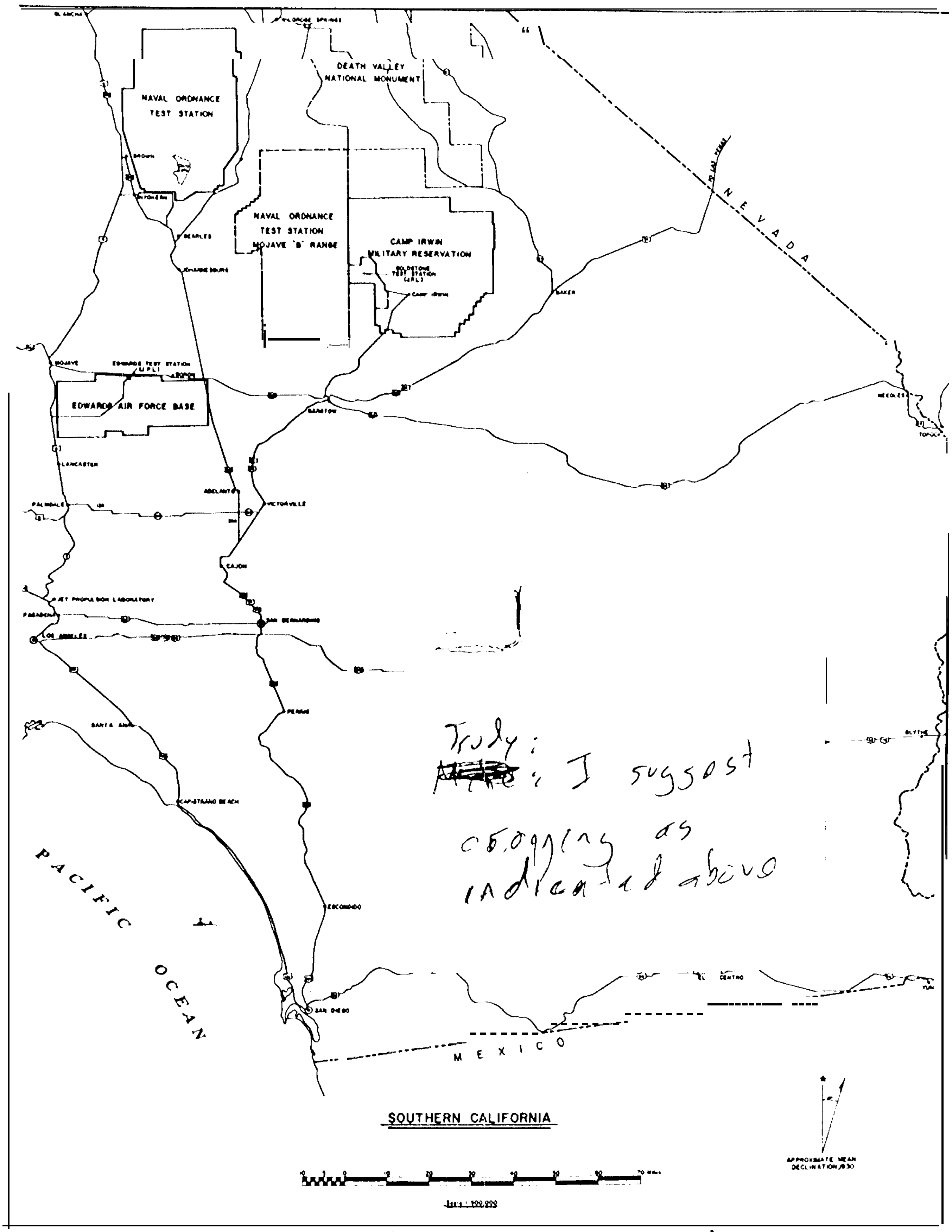


Fig. 5 Model of 26 [illegible] antenna



Truly: ~~Mike~~: I suggest cropping as indicated above

Fig. 6 Map of Goldstone and Surrounding Facilities

Fig 7 26 m diameter at Goldstone under construction

Fig 8 Completed antenna at Goldstone and Surrounding terrain

2

Table 4. Summary of Requirements for Space Probes and Satellite Programs[a]

Mission	Inclination (°)	Altitude (mi)	Telemeter Bandwidth	Required Telemeter Time/Orbit (min)	Orbit Data Requirements	Geometrically Best Station Latitude (°)	Latitude Tolerance of Geometrically Best Location (°)	Geometrical Minimum No. of Stations	Probable No. of Stations	Probable Locations
Non copper Satellite	40-90	100-300	2 cps	3	high speed low accuracy	25-30	10	3-6	3-6	25-30
Communications Relay Satellite	0	24,000	3 mc	continuous	low speed low accuracy	0	60	3	12	temperate zone
Scientific Satellite	90	100-3,000	100 kc	3-10	low speed high accuracy	90	15-50	1	12	0-90
Lunar Probe	± 28 (max)	3×10^5	30 cps—10 kc	continuous	low speed high accuracy	0	35	3	3-6	0-40
Interplanetary Probe	± 23½ (max)	50×10^6 5×10^8	30 cps—3 kc	continuous	low speed high accuracy	0	35	3	3-6	0-40
Communications Courier Satellite	0	1,200 (2,000)	3 mc	3-10	low speed low accuracy	0	30	3, 6	12	low temperate zone
Reconnaissance Satellite	90	300	60 mc	*3	low speed high accuracy	90	15	[illegible]	4	20-60 (N)
Meteorological Satellite	90	300	6 mc	3	low speed low accuracy	90	15	[illegible]	4-6	20-60 (N)
Man In Space, Equatorial	0	200	50 kc tel 3 mc video 3 kc voice	10	high speed high accuracy	0	10	[illegible]	4-12	0-10
Man In Space, Soonest	30-40	200	50 kc tel 3 mc video 3 kc voice	10	high speed high accuracy	35	5	2	12-24	0-40
Man In Space, Soonest, Alternate	30-40	200	100 kc tel 6 mc video, time-spaced with photographs 3 kc HF radio voice continuously	5	high speed high accuracy	35	5	[illegible]	6-12	0-40

[a] Slow speed is defined as orbit determination after several passes (or hr.; high speed, after one pass (1 hr). Low accuracy is on the order of 1 part in 100; high accuracy, 1 part in 1,000 or better.

3

Table

JPL-Proposed Lunar and Planetary Miss...

	Payload Number	Date	Mission	Scientific Package Weight (kg)	Gross Payload Required Weight (kg)	Gross Payload Available Weight (kg)	Nature of Measurements
Firm	1	1 July 1960	Circumlunar	17	159	230	Fields, atmosphere, photos of surface.
	2	10 Oct. 960	Escape toward Mars	4	161	135	Interplanetary conditions, photos of Mars.
	3	3 Oct. 1960	Escape toward Mars	14	161	135	Interplanetary conditions, photos of Mars.
	4	22 Jan. 96	Escape toward Venus	14	161	35	Interplanetary conditions, photos of Venus.
	5	25 Jan. 1961	Escape toward Venus	14	161	35	Interplanetary conditions, photos of Venus.
	6	Sept. 1961	Escape out of ecliptic	9	120	135	Interplanetary conditions, measure A. U.
	7	Apr. 1962	Lunar satellite	23	233	230	Gamma-rays, high-resolution mapping.
	8	30 Aug. 1962	Venus satellite	1180[a]	770	1360	Atmosphere, fields, surface nature.
	9	2 Sept. 1962	Venus satellite	180[a]	770	1360	Atmosphere, fields, surface nature.
	10	30 Nov. 1962	Mars yby	4	190	135	Atmosphere, photos, magnetic, and cosmic ray.
	11	3 Dec. 1962	Mars lyby	.	90	135	Atmosphere, photos, magnetic, and cosmic ray.
	2	June 1963	Circumlunar & return	1570[b]	2300	2300	Development test for Venus landing.
	13	963	unar soft landing	23	2300	2300	Surface analysis, seismography.
	1	963	Lunar soft landing	23	2300	2300	Surface analysis, seismography.
Tentative	15	28 Mar. 1964	Venus landing	1100[b]	2050	?	Weather, surface exploration.
	16	1 Apr. 1964	Venus landing	1100[b]	2050	?	Weather, surface exploration.
	17	Aug. 1964	Circumlunar and return	1570[b]	2300	2300	Manned flight.
	18	20 Jan. 1965	Circum-Mars and return	2200[b]	4500	?	[illegible]

[a]Including 1100-kg retrorocket.
[b]Including aerodynamic heating protection and aerodynamic controls or brakes, or both.
SOURCE: J. D. McKenney, "Minutes of the Meeting of the NASA Program Study Committee . . . ," 16 Jan. 1959.

Fig. 9 Woomera antenna components at Port of Los Angeles

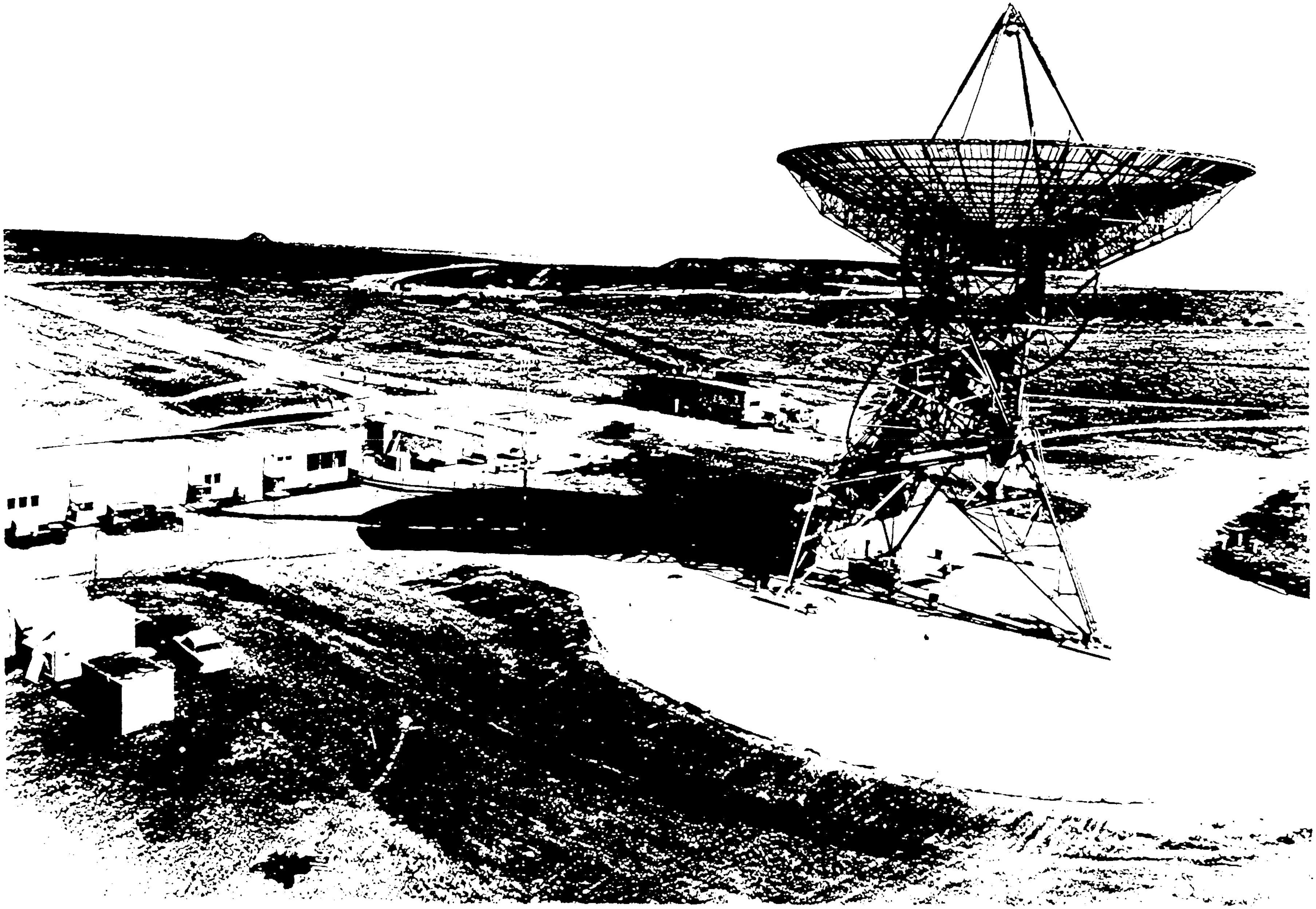
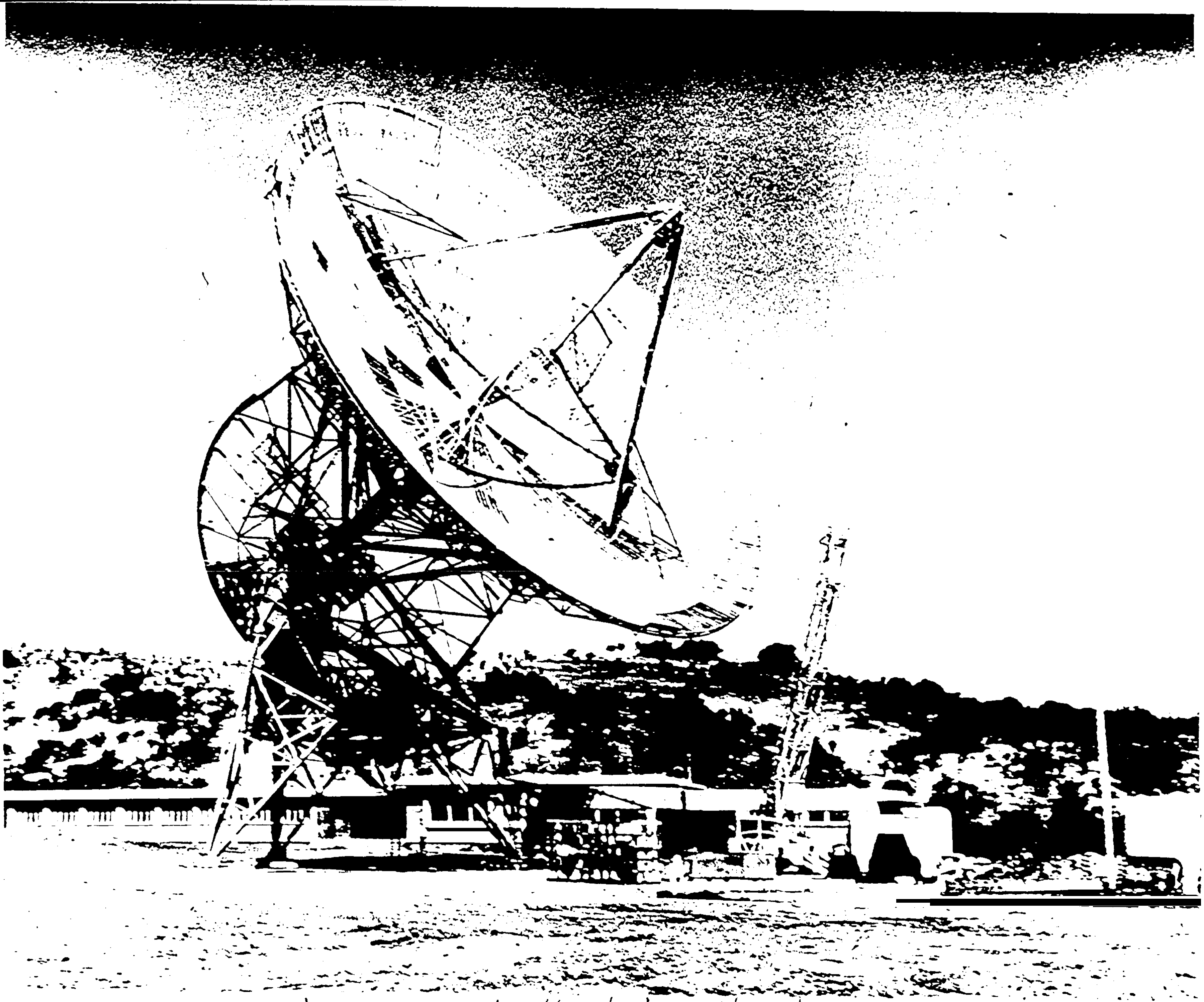


Fig 10 Completed Woomera antenna

Fig. 1 Installation of reflector surface panels at Hartebeesthoe



ig 12 Completed antenna at Hartebeesthoek

DSIF TRACKING SUPPORT

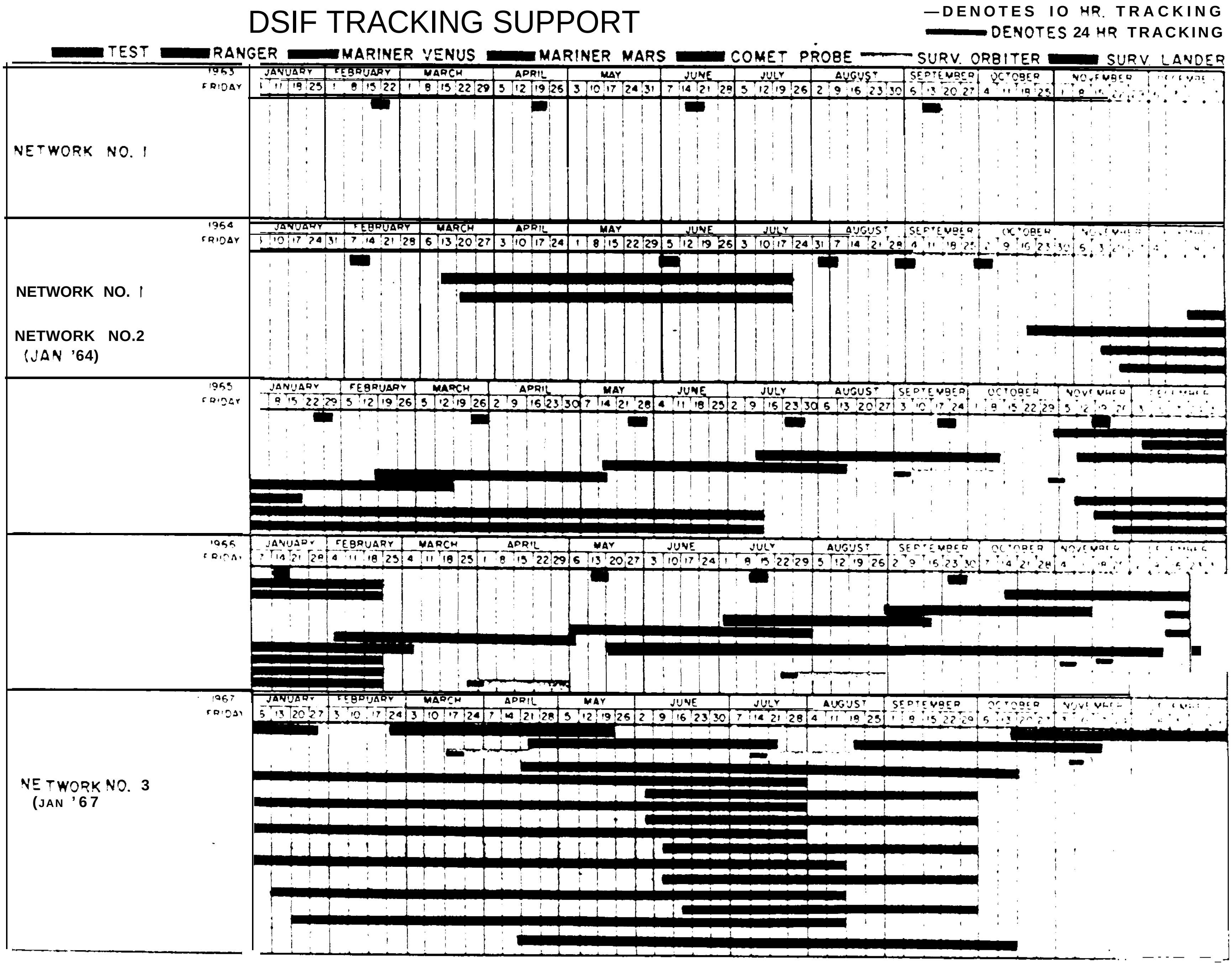


Table 4 Projected space-probe tracking support 1963-1967

Fig. 13 Tidbinbilla station

NASA G-67-8833

Figure 14 Robledo station

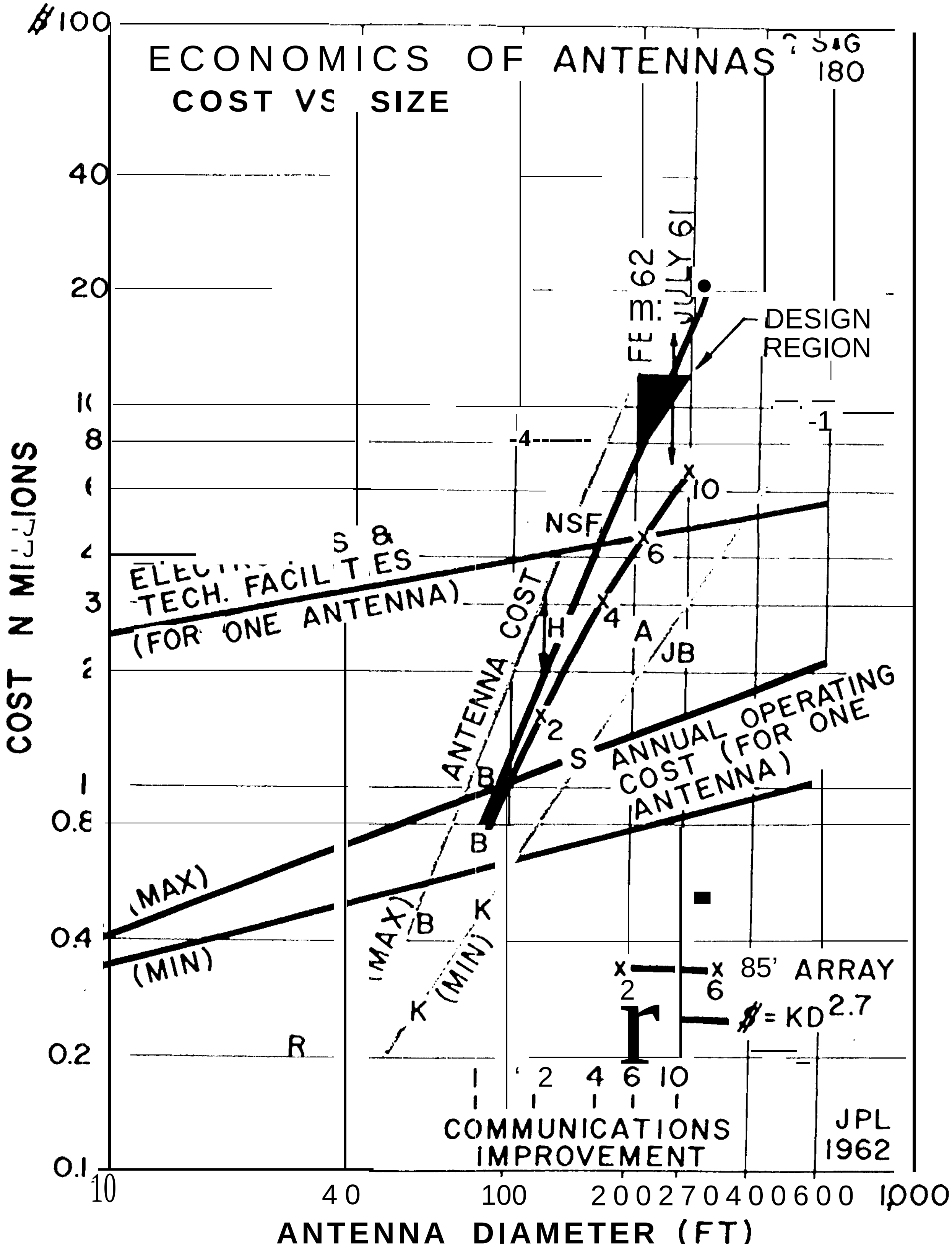


Figure 15 Economics considerations for Advanced Antenna System

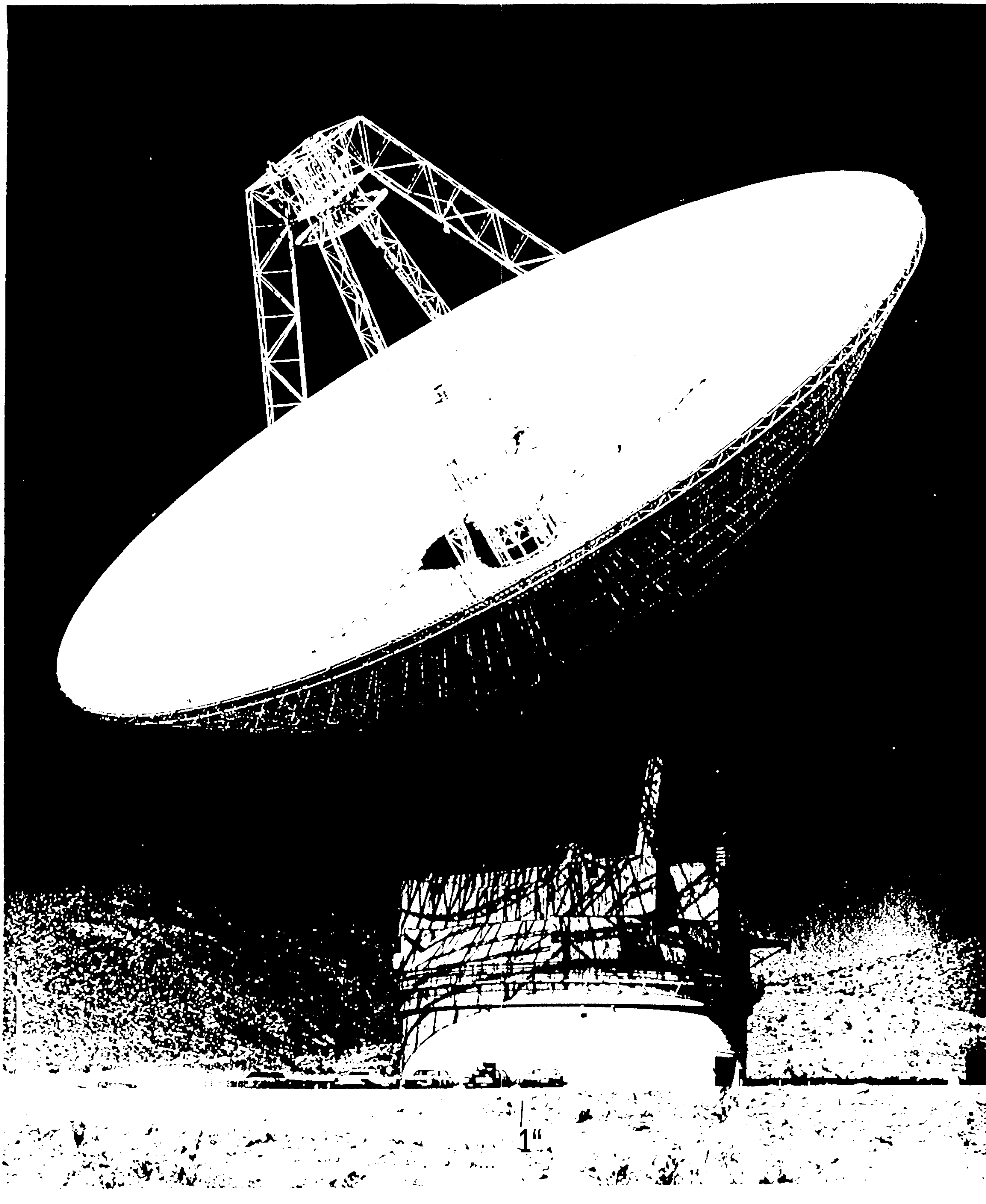
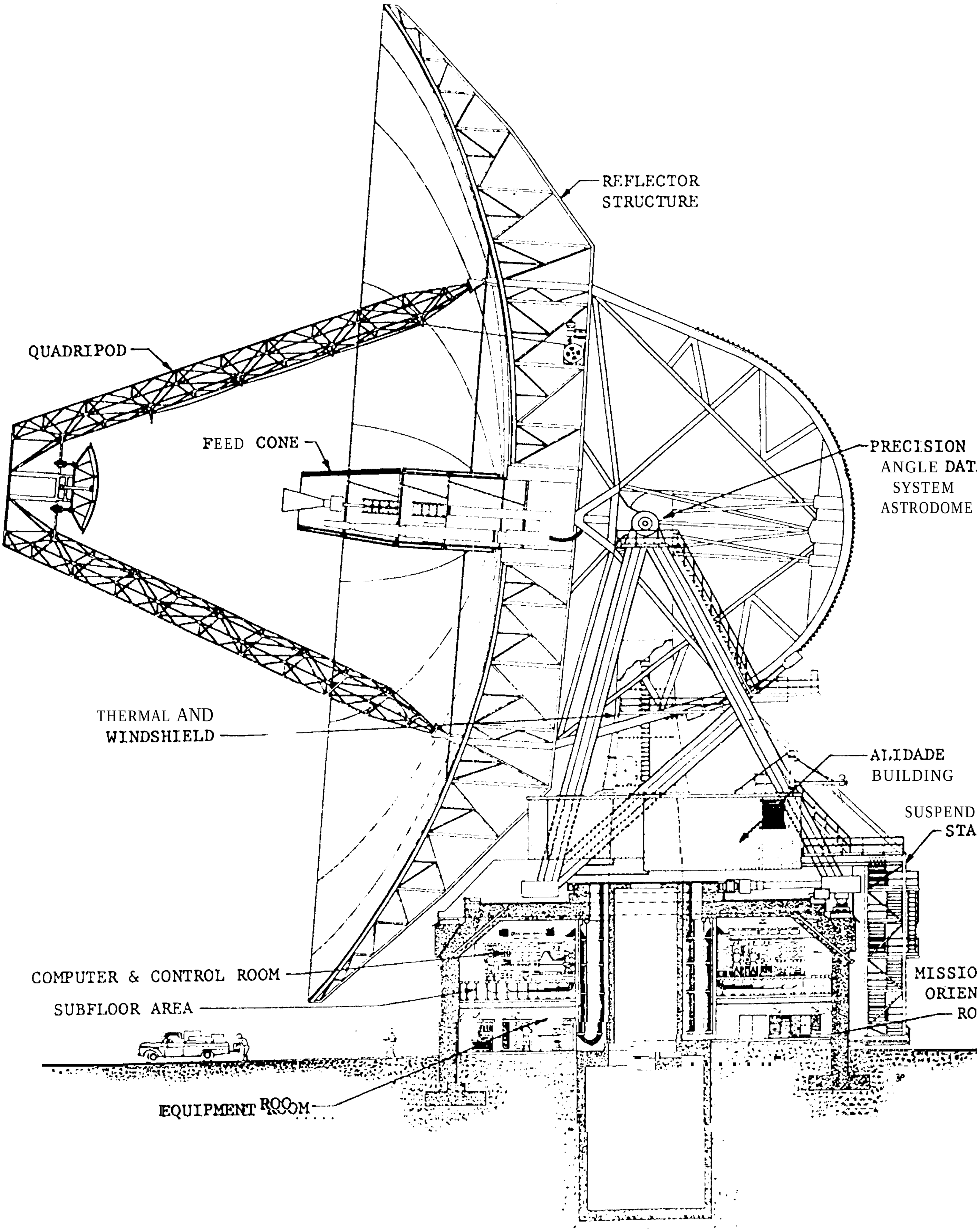


Figure 16 Goldstone 210-ft (64-m) antenna
[illegible]



Enclosure 1
Attachment 1

SIDE ELEVATION & SECTION

Figure 17. Diagram of 210 Ft. diameter (64 m) antenna

34-METER *STANDARD ANTENNA HISTORY*

The 34-meter standard (STD) antennas were installed and became operational at Goldstone in 1961, and Australia and Spain in 1965. All three antennas were originally equipped with 26-meter (85-foot) reflectors and operated at S-band (2.3 GHz) frequencies. Their mechanical design (Figures 3, 6, and 7) is nearly identical to a radio astronomy antenna developed in the 1950s for the University of Michigan and the Associated Universities, Incorporated. The equatorial mount, which provides an hour-angle/declination pointing system, is designed to track a celestial object (spacecraft) at the Earth's sidereal rate (0.004 degree/second) with minimum or no movement of the declination axis. A Cassegrainian focal system is used, with the electronics for the first stage of amplification located in a feed cone at the center of the reflector.

To add X-band (8.4 GHz) capability and increase the antenna gain (received signal strength) for outer planet missions, the reflector diameters were extended to

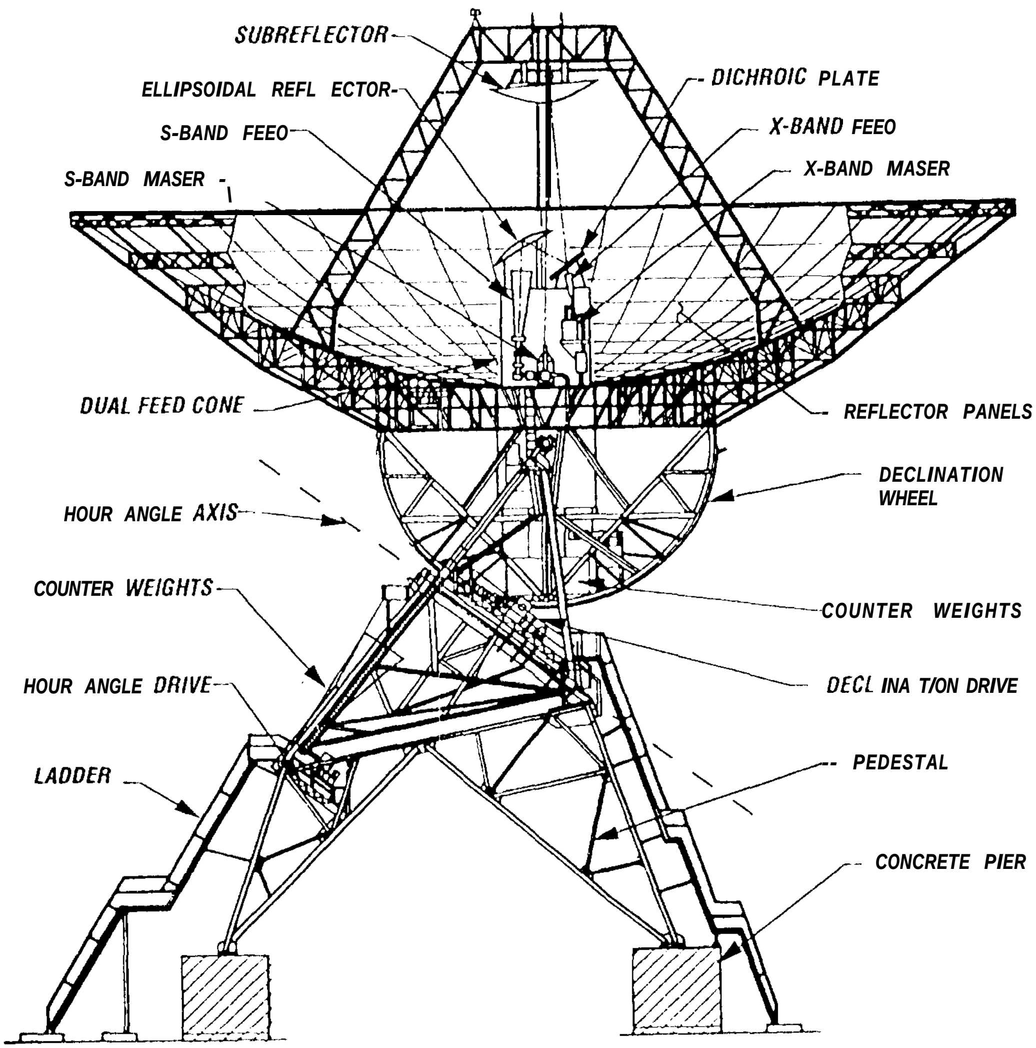


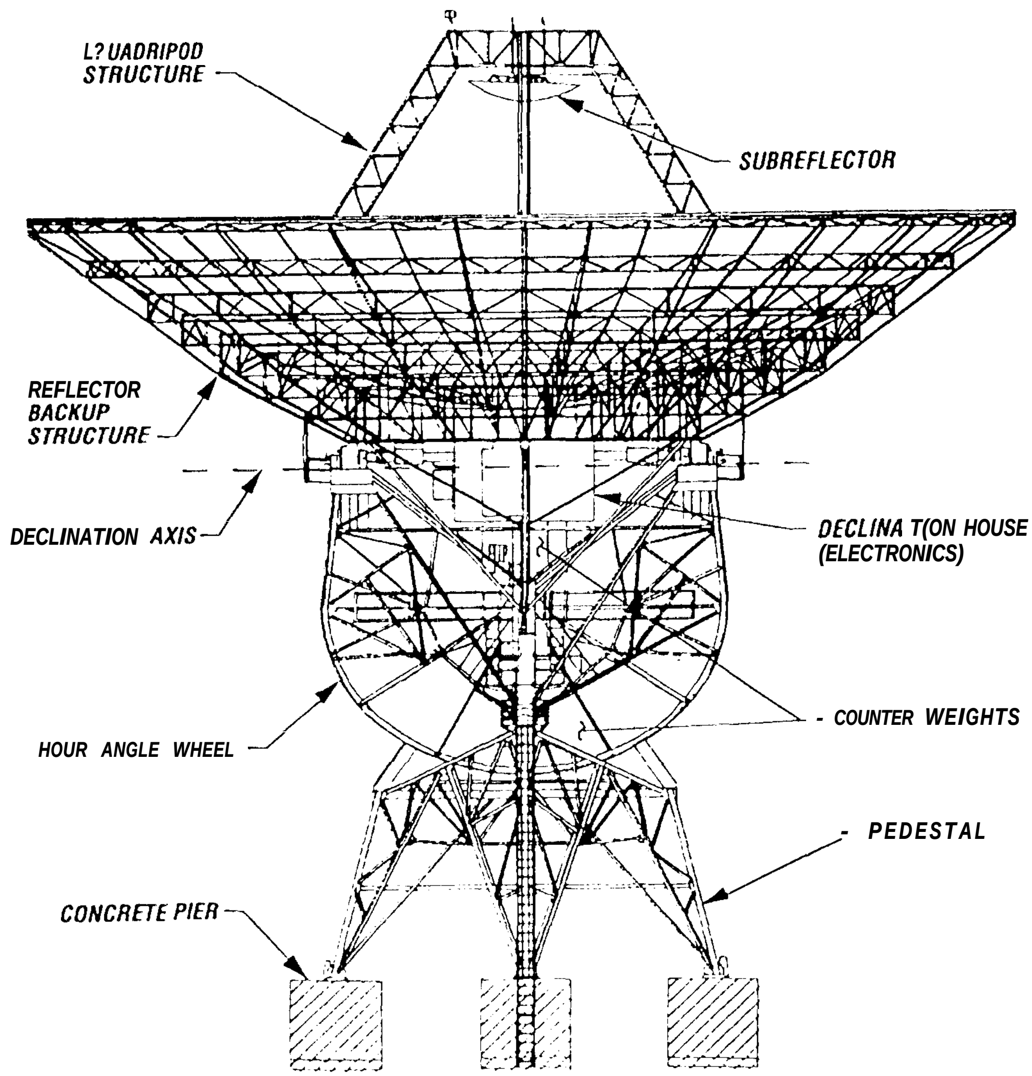
Figure 8. '34-meter standard (STD) antenna details, side elevation.

34 meters (1 11 feet) at Goldstone in 1978 ant{ Spain and Australia in 1980.

Over their operating lifetimes, all three antennas have experienced serious structural and mechanical breakdown problems, primarily due m the nonsymmetric distribution of weight carried by the hour *angle* axis, which moves the dish reflector from the ease to the west horizon. During the 26-to-34-meter conversion, the final [rim-weight added to counterbalance the reflector significantly increased [he weight and flexure of the moving structure. This additional force has resulted in gear mesh separation, and a much higher load on the axis bearings. Over time the added stress has caused an increasing number of cracked welds and bolt failures. An engineering report and photo documentation on these problems are provided in Part II of this paper.

Gear Mesh Separation

Excessive declination drive gear separation occurs as the antenna is driven from the east to the west horizon. The separation is clue to an 0.25-inch (6 millimeter) deflection of the hour angle gear wheel, which results in a marginal declination gear tooth engagement at the west horizon. The separation has caused gear teeth [o jump, breaking the drive gear on two occasions at Goldstone and three occasions overseas.



18 B

Figure 1. 34-meter standard (STD) antenna details, rear elevation.

MULTIFREQUENCY ANTENNA DESCRIPTION

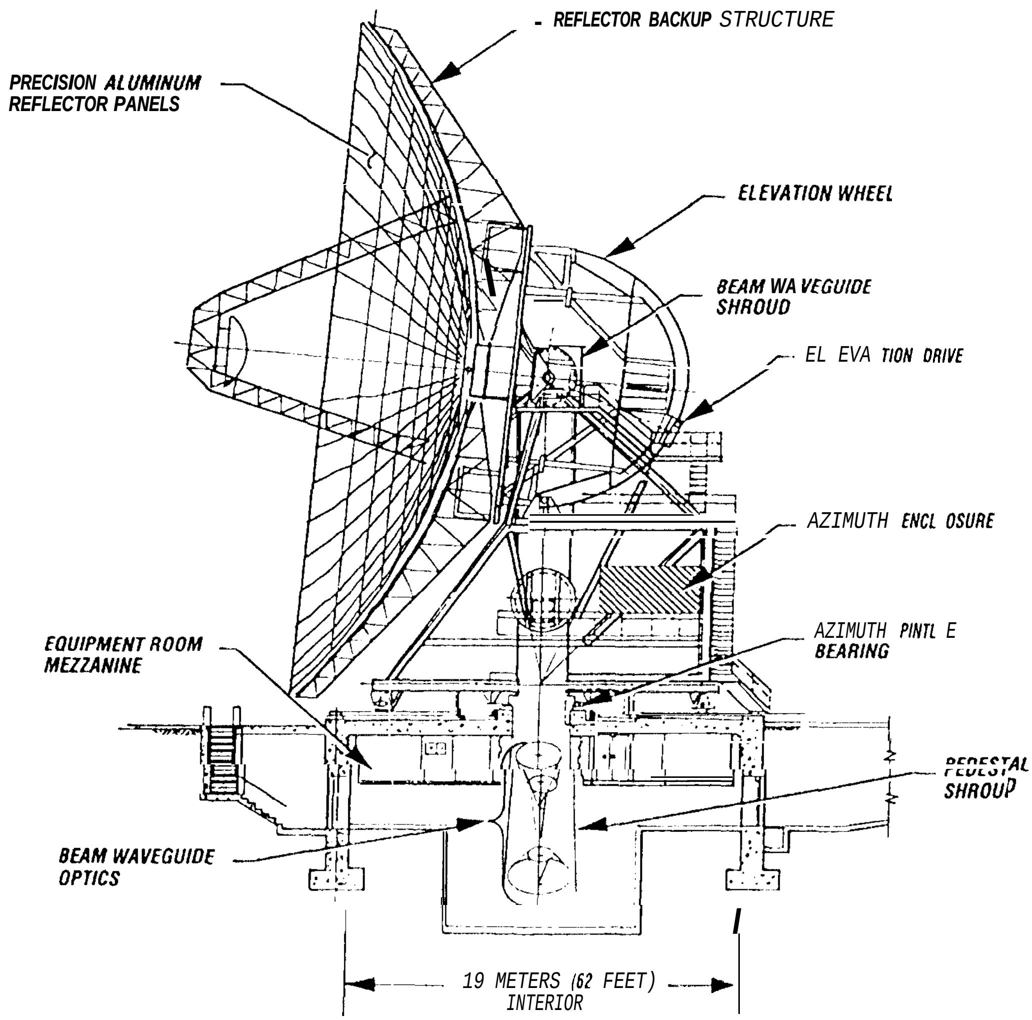
A beam waveguide is an optical system that uses a series of flat and curved mirrors to guide the received spacecraft signal (the beam) clown from the antenna reflector [o the low-noise amplifiers located in the underground equipment room in the antenna pedestal. (See Figures 9 and 10.)

The system employs dichroic mirrors to separate and direct the S, X, and K-band signals to their respective low-noise amplifier feeds. A dichroic mirror transmits (lets through) higher radio frequencies in a multifrequency beam while reflecting a desired lower frequency to its feed.

The antenna's 34-meter reflector and elevation wheel are supported on a trussed alidade structure that provides a nonflexing rigid support. The complete structure rotates in azimuth on a wheel and track assembly anchored to the 67-foo[diameter concrete pedestal. Unlike [he Network's current compliment of an-

19A

Figure ●. Multi-frequency antenna design, side view.



tennas, which have receiver and trans-mitter electronics installed on the moving antenna reflector, the pedestal allows routine access for repair, replacement, and upgrading of electronics equipment without interrupting scheduled tracking operations.

The overall integrity of the structure to withstand wind, gravity loadings, anti inertias provides a compensated pointing accuracy of 0.006 degree.

Increased Antenna Efficiency

Compared to the STD antenna, the increased efficiency and low-noise performance of the beam waveguide antenna will provide an increase in si~gn:ll-to-noise ratio of 2 to 3 dB at X-band and 0.5 to 1.0 dB at S-band. The improvement at X-band and the later addition of K-band will add significantly to the effective communication range of the Network (i. e., the reception of sub-stantially higher data rates over longer distances), and relieves Network loading on the 70-meter antenna subnet.

For example, based on current Network capabilities, the 1996 Cassini mission to Saturn and the 1998 Mars Rover Sample Return mission are both designed as X-band missions. Both have high data rate requirements that will

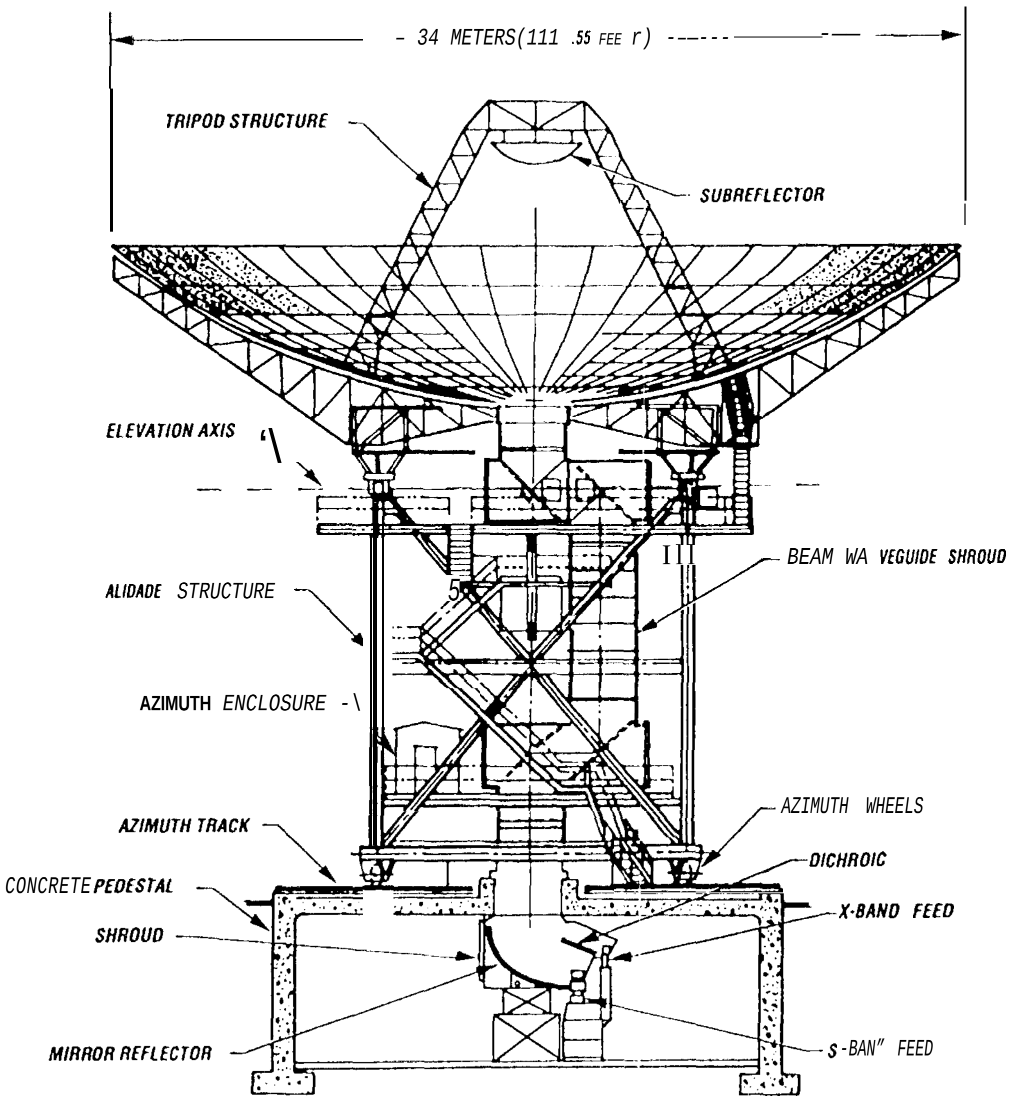
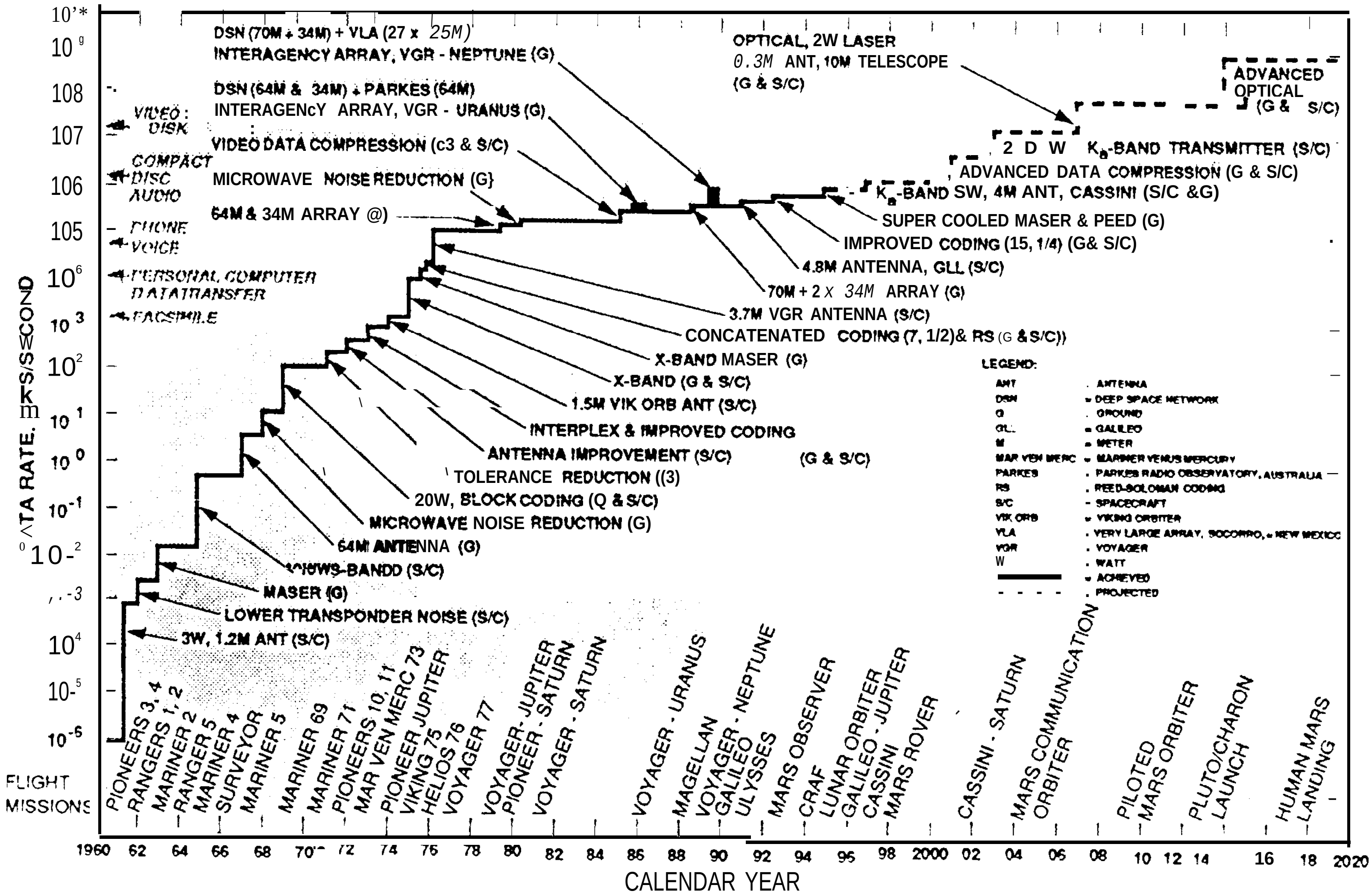


Figure [illegible]. Multi-frequency antenna, rear vie w.

PROFILE OF DEEP SPACE COMMUNICATIONS CAPABILITY

SPACE-TO-EARTH

EQUIVALENT IMAGING DATA RATE CAPABILITY AT JUPITER DISTANCE -750 MILLION KILOMETERS



This chart documents the twelve orders of magnitude improvement of deep space communications capability since the beginnings of deep space exploration to the present. Another 3 orders of magnitude Improvement are forecast by 2020. The Increase of performance Is due to a series **of Innovative cooperative improvements In both the spacecraft** and ground. Key factors Include **higher operating frequency and Improved coding techniques, spacecraft higher power and antenna size, and ground system fewer noise amplifiers and Increased antenna size.**

6485-27831 .

Figure 20

Jet Propulsion Laboratory
California Institute of Technology
4800 Oak Grove Drive
Pasadena, California 91109
(818) 354-4321

RECEIVED
MAY 12 1989
N. A. RENZETTI

Info G Waff

JPL

5/2

May 8, 1989

Refer to: 440-101 /RJA:mt

John A. Paulsen, 1Lt, USAF
4945 S. Carefree Cir
Colo. Spgs . CO 80917

Dear Sir,

The following is in response to your request of March 17, 1989 addressed to Dr. N. A. Renzetti :

1. The call signs of the Deep Space Stations (DSS) are identified by numbers and used in voice communications as "station nn".

CALL SIGN				PRIMARY USE	SITE NAME	SIZE
Goldstone Deep Space Communication Complex (GDSCC)						
Deep	Space	Station	12	D/S Ops/Testing	Echo	34m
"	"	"	13	R & D	Venus	34m
"	"	"	14	D/S Ops/Testing	Mars	7 0m
"	"	"	15	D/S Ops Testing	Uranus	34m
"	"	"	16	N/E Ops/Testing	n/a	26m
"	"	"	17	N/E Ops/Testing	"	9 m
Canberra Deep Space Communication Complex (CDSCC)						
Deep	Space	Station	42	D/S Ops/Testing	n/a	34m
"	"	"	43	D/S Ops/Testing	"	7 0m
"	"	"	45	D/S Ops Testing	"	34m
"	"	"	46	N/E Ops/Testing	"	26m
Madrid Deep Space Communication Complex (CDSCC)						
Deep	Space	Station	62	D/S Ops/Testing	n/a	34m
"	"	"	63	D/S Ops/Testing	"	7 0m
"	"	"	65	D/S Ops/Testing	"	34m
"	"	"	66	N/E Ops/Testing	"	26m
Other stations						
Merritt Island,		MIL	71	D/S Launch Ops/Test	n/a	n/a
JPL Pasadena,		CTA	21	S/C Ops/Testing	"	n/a

D/S = Deep Space
N/E = Near Earth

Table 5"

TABLE 1 - ANTENNA IDENTIFIERS

ID#	DESCRIPTION	LOCATION	DEGREES LONGITUDE	BAND	CATEGORY
1					
2					
3					
3	11M	CTA-21			
	SEE TABLE 2				
5	34M STD	[illegible]			
6	70M	CTA-21			
7	34M HEF	CTA-21			
8	26M	CTA-21			
9	34M BWG	CTA-21			
10	SEE TABLE 2				
11	26 M	GOLDSTONE		S	RETIRED
12	34M STD	GOLDSTONE	243	S,X	A,B
13	34M BWG	GOLDSTONE		S,X,K	B
14	70M	GOLDSTONE	243	S,X,L	B
15	34M HEF	GOLDSTONE	243	S,X	B
16	26M	GOLDSTONE	243	S	A
17	9M	GOLDSTONE	243	S	A
18					
19	VLA	SOCORRO			B
20	SEE TABLE 2				
21	SEE TABLE 2				
22					A
23	11M	GOLDSTONE	243	S,X,K	A,B
24	34M BWG	GOLDSTONE		S,X,K	A,B
25	34M BWG	GOLDSTONE	PROPOSED		A,B
26	34M BWG	GOLDSTONE	PROPOSED	S,X,K	A,B
27	34M BWG	GOLDSTONE	PROPOSED	S,X,K	A,B
28					
29					
30					
31					
32					
33	11M	TIDBINBILLA			A
34	34M BWG	TIDBINBILLA	148		A,B
35	34M BWG	TIDBINBILLA	PROPOSED	S,X,K	A,B
36	34M BWG	TIDBINBILLA	PROPOSED	S,X,K	A,B
37	34M BWG	TIDBINBILLA	PROPOSED	S,X,K	A,B
38					
39					
40	SEE TABLE 2				
41	26M	WOOMERA	136	S	RETIRED
42	34M STD	TIDBINBILLA	148	S,X	A,B
43	70M	TIDBINBILLA	148	S,X	B
44	26M	HONEYSUCKLE		S	RETIRED
45	34M HEF	TIDBINBILLA	148	S,X	B
46	26M	TIDBINBILLA	148	S	A
47	70M	USSURIYSK	131		
48	64M	USUDA	138	S,X	A,B
49	64M	PARKES	148		B

- Table 6A

TABLE 1 — ANTENNA IDENTIFIERS

ID#	DESCRIPTION	LOCATION	LONGITUDE	BAND	CATEGORY
50					
51	26M	JOHANNESBURG	27	S	RETIRED
52	70M	EVPATORIYA	33		
53	11M	ROBLEDO			A
54	34M BWG	ROBLEDO	•	S,X,K	A,B
55	34M BWG	ROBLEDO	PROPOSED	S,X,K	A,B
56	34M BWG	ROBLEDO	PROPOSED	S,S,X,K	A,B
57	34M BWG	ROBLEDO	PROPOSED	S,X,K	A,B
58					
59					
60	SEE TABLE 2				
61	34M STD	ROBLEDO	355	S,X	A,B
62	26M	CEBREROS	•	S	RETIRED
63	70M	ROBLEDO	355	S,X	B
64					
65	34M HEF	ROBLEDO	355	S,X	B
66	26M	ROBLEDO	355	S	A
67	15M	BONN			RETIRED
68	30M	WEILHEIM	11	S,X	B
69		EFFELSBURG			RETIRED
70	SEE TABLE 2				
71	SEE TABLE 2				
72		MIL 71			
73	9M	GREENBELT	283	S	A
74	9M	SANTIAGO	289	S	A
75					
76	9M	WALLOPS	284	S	A
77					
78	9M #1	BERMUDA	295	S	A
79	9M #1	MERRITT IS.	279	S	A
80					
81					
82					
83					
85					
87					
88	11M	GREENBANK	PROPOSED		
89	100M	GREEN BANK	107		
91					
92					
93					

Table 6B

TABLE 2- FACILITIES

ID#	FACILITY	LOCATION	DESCRIPTION
4	SPC	CTA21	SIGNAL PROCESSING CENTER
10	GCF, SPC	GOLDSTONE	1. GCF: GROUND COMMUNICATIONS FACILITY 2. SIGNAL PROCESSING CENTER
20	GCF	JPL	GROUND COMMUNICATIONS FACILITY in Bldg 230
21	CTA	JPL	COMPATIBILITY TEST AREA in Bldg 125
40	SPC	TIDBINBILLA	SIGNAL PROCESSING CENTER
60	SPC	MADRID	SIGNAL PROCESSING CENTER
70	SPC	MILA	SIGNAL PROCESSING CENTER
71	MIL-71	MILA	MIL-71 LINK
91	NDP	JPL	NETWORK DATA PROCESSING area in Bldg 230
92	NVP	JPL	NOCC VLBI PROCESSOR area in Bldg 230

Table 6C